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REPORT ON THE EFFECT OF YAW ON ARMOR PENETRATION AND OF GUN TEMPERATURE ON YAW

H. H. Zornig, et al

Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

11 November 1936

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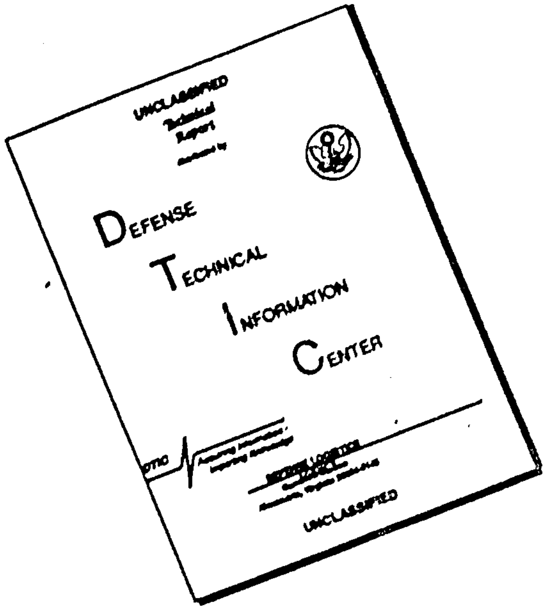

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REPORT ON THE EFFECT OF YAW ON ARMOR PENETRATION AND OF GUN TEMPERATURE ON YAW

by

H. H. Zornig
J. R. Lane

November 1936

U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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Report No. 42

JRL/emh
Aberdeen Proving Ground, Md.
November 11, 1936

REPORT ON THE EFFECT OF YAW ON ARMOR PENETRATION AND OF GUN TEMPERATURE ON YAW

Project KST 101 - Determination of the Effect of the Pitch of Rifling on Caliber .50 Machine Gun.

Abstract

Section I - Effect of Yaw on Armor Penetration

Firings were carried out in caliber .50 barrels of various twists of rifling in an effort to determine the optimum one but with no conclusive result. The armor penetration was determined as a function of the yaw and it was found that the effect of yaw was negligible on penetration as compared with its effect on accuracy at long ranges.

Section II - Effect of Gun Temperature on Yaw

It was found that a relatively large percentage of rounds fired in a hot gun with caliber .50 M1 Ball and A.P. boat-tail bullets have appreciable yaws whereas the M1 Tracer flat-base bullet and several modifications of this bullet give much smaller yaws. Recommendations are made for additional tests with modified bullets and a gun having a modified throat contour before any additional work is done on the determination of the optimum twist of rifling.

In an attempt to improve the performance of the caliber .50 Machine gun and ammunition, a study was begun of the effect of changing the pitch of rifling from the standard of one turn in 15 inches. The best pitch of rifling was to be determined for M1 ammunition loaded to 2500 f/s instrumental velocity where the criterion for best pitch of rifling was to be the penetration of armor plate at 50 yards. After the best pitch was determined for the M1 bullet at 2500 f/s both the M1 and T2E1 bullets were to be fired at velocities of 2500 f/s, 2700 f/s and 3000 f/s. From these firings, the most satisfactory

combination of pitch, bullet and velocity was to be fired for accuracy life in comparison with M1 ammunition.

A resume of the preliminary results was made in the 2nd Indorsement to O.O. 471.4/4370, A.P.G. 471.4/255-2. Three pitches of rifling (1 in 13-1/2", 1 in 14", and 1 in 14-1/2") had been used in the firing but there was no difference in the penetration obtained. In view of this inconclusiveness, the program of firings was amended.

The amendments in the program were made in order to obtain the following information which was thought necessary for a well-founded judgement concerning the best combination of pitch of rifling, muzzle velocity and bullet:

(1) The armor penetration as a function of the yaw and velocity.

(2) The yaw and velocity of the bullet as a function of the range, of the pitch of rifling and of the number of rounds fired.

Since the gun is often fired when hot, information is also desired of the effect of firing from a hot gun. This may be obtained by heating a gun electrically and maintaining a certain temperature while firing.

Section I - Effect of Yaw on Armor Penetration

Caliber .50 Armor Penetration Firing

Four barrels were used with twists varying from one turn in 15" to one turn in 12", at intervals of one inch. The bullets used were caliber .50 M1 A.P. and T2E1. The velocities at which the firings were carried out were approximately 2000, 2500 and 3000 f/s. The plate fired against was Class B, either 3" or 1" thickness.

In order to determine the effect of yaw on the penetration, yaw cards were placed at a distance of about one foot in front of the plate; it is assumed that the nutational yaw is damped out at a range of 50 or 100 yards and that the yaw is due to precession alone. If this is true, then one card, placed 12" in front of the plate, is sufficient for the measurement of the yaw. Velocities were measured in the usual way by the Aberdeen Chronograph. The penetration

in the armor plate was obtained by a special gauge which measured the slant penetration and the angle of the hole from the normal.

As the yaws obtained by firing the normal M1 and T2E1 bullets were negligible, several rounds were fired with nicked bullets. Nicking consists of filing or cutting away a small section, weighing from 5 to 15 grains, from the jacket of the bullet, thus making the bullet eccentric and imparting to it a large yaw.

Data and Results:

Table I at the end of this report gives a complete record of the measurements taken. The measured penetration is that obtained by means of the gauge and is taken along the axis of the hole. The corrected penetration is derived by multiplying this measured penetration by the cosine of the angle between the normal and the axis of the hole. The yaws are those obtained from the cards placed in front of the plate.

In order to be able to compare the relative efficiencies of the two bullets fired at various velocities with different twists of rifling, the deMarre Coefficient (K) was computed for each round. Table II gives the mean K for each combination when the yaw is negligible and the individual K etc. when the yaw is significant.

An examination of this table shows conclusively that the penetration at 100 yards is independent of the twist of rifling. As between the two types of bullets, it is also obvious that the M1 A.P. is better than the T2E1.

Effect of Velocity on Penetration

As stated previously, the firings were carried out at three different velocities, 2000 f/s, 2500 f/s, and 3000 f/s. The deMarre Coefficients are significantly higher for the rounds fired at 3000 f/s than for those fired at 2500 f/s. Since the yaws and the differences in velocity from round to round are negligible, it would be interesting to compare the actual penetrations obtained at each velocity for the two bullets.

Table III - Mean Penetrations and deMarre Coefficients

Muzzle Velocity/Bullet →	M1 A.P. Penetration	K	T2E1 Penetration	K
2000 f/s	1.14	.92	.94	1.07
2500	1.53	.91	1.35	1.02
3000	1.61	1.09	1.43	1.19

While the penetrations are somewhat greater at a muzzle velocity of 3000 f/s than at 2500 f/s, the increase is not as great as would be expected. However, it is not important that the penetrative power be an optimum at this velocity since, under service conditions, the striking velocity is considerably lower than the muzzle velocity.

Penetration vs Yaw

As stated previously, in order to get significantly large yaws, resort had to be made to nicking. In this way abnormal yaws varying widely from round to round depending probably upon the nature of the nicking, were obtained. The deMarre Coefficients were computed for these rounds and are shown plotted against the yaw on Plots No's 1 and 2. It is evident from these plots that the deMarre Coefficient increases with the angle of yaw, as was expected. However, the rate of increase of the deMarre as a function of the yaw is not the same for the three velocities. This rate was computed by the method of least squares for the two bullets at a velocity of 2500 f/s and found to be about .02, i.e., the deMarre Coefficient at any yaw is equal to the value at 0° yaw plus .02 times the angle of yaw in degrees.

The equations for the two bullets are

M1 A.P. : $K = .91 + .021\delta$

T2E1 : $K = 1.02 + .019\delta$.*

* In obtaining this equation the point corresponding to a yaw of 30 was not considered because of its variation from the other determinations.

where K is the deMarre Coefficient and δ is the angle of yaw in degrees. An increase in K of .02 for each degree of yaw is not important, since the bullet would be apt to miss its target completely at a yaw great enough to decrease significantly its penetration.

Oblique Impact

Several rounds were fired at oblique impact (30° from normal) with 0° yaw and also with nicked bullets giving larger yaws. With the same bullet, the penetration is, of course, greatest when the trajectory of the bullet is normal to the plate. A formula has been derived for the computation of the deMarre when the angle of penetration is not normal to the plate:

$$K = K_o \left[1 + \lambda(\sec.\ \theta - 1) \right]$$

where K_o is the deMarre at normal impact, θ is the angle of impact measured from the normal and λ is an experimental constant. λ was computed for the two bullets and found to be

M1 A.P.	-2.20
T2E1	-3.87

From this, it is seen the M1 A.P. bullet is better than the T2E1 at oblique impact as well as at normal.

The deMarre Coefficients for the T2E1 nicked bullets fired at 30° penetration are very much greater than those for the M1 A.P. nicked bullets, as may be seen from Plots Nos. 1 and 2. This bears out the superiority of the M1 A.P. bullet.

Discussion of deMarre Coefficient

Reference has been made throughout this report to the deMarre Coefficient. Strictly speaking the coefficient computed and used is not the deMarre Coefficient but a function probably proportional to it. The deMarre Coefficient (K) is defined for the caliber .50 bullet by the following equation:

$$K^2 = \frac{B.\ L.}{6153\sqrt{t^3}}$$

where B. L. is the Ballistic Limit and t is the thickness of plate penetrated. In these tests, however, the plate

was of 3" thickness so that it was never completely penetrated; t was taken as the actual distance penetrated corrected for the angle of penetration by multiplying by the cosine of the angle that the hole in the plate makes with the normal. The result of measuring the thickness in this way is that the deMarre Coefficients obtained are somewhat higher than they would be if t represented complete penetration.

For some of the firing with nicked bullets, the plate was placed at a distance of 50 yards in front of the muzzle. For the firing with nicked bullets at oblique penetrations, a 1" plate was substituted for the 3" plate. These changes should not have any significant effect on the results.

Summary of Results: Caliber .50 Plate Firings

From the caliber .50 armor plate firing data, no significant differences are discernible between the various twists of rifling used.

The M1 A.P. bullet is decidedly superior to the T2E1.

Although the penetration is slightly better at 3000 f/s velocity than at 2500 f/s, the difference is not nearly as great as would be expected from an a priori consideration of the 20% increase in velocity. However, the rounds fired at 3000 f/s muzzle velocity will have greater penetrative power at long ranges than rounds fired at lower velocities.

The deMarre Coefficient is found to be approximately a linear function of the yaw, and may be expressed by the equation

$$K = K_o + .02\ \delta,$$

where K_o is the deMarre at 0° and δ is the yaw in degrees, the velocity being 2500 f/s. The yaw therefore, will be too great to admit accurate shooting before it will have an appreciable effect on the penetration.

Caliber .30 Armor Penetration Firings

To determine the effect of yaw on penetration of face-hardened plate, the caliber .30 M1922 A.P. bullet was fired against 1/4" plate. Large yaws were obtained either by firing from an old marred barrel or by nicking the bullets. In this series of firing the velocities and yaws were measured as in the caliber .50 firing, but the penetrations obtained were indicated only as either complete or partial since the depth could hardly be obtained on this type of plate.

The data obtained from these firings are given in Table IV at the end of this report; the striking velocities and the yaws are included in this table. In order to present the data more clearly, Plots Nos. 3 and 4 were drawn up showing the Kinetic Energies against the yaws and also distinguishing between complete and partial penetrations. From a study of the plots it is evident that the greater the Kinetic Energy of the bullet, the better is the chance of complete penetration; however, this is a truism which does not need these firings for confirmation. As far as the effect of yaw is concerned, the results are not conclusive; on the whole, a bullet with a pronounced yaw is not as effective as one without any yaw but it is not possible to develop an empirical relation between yaw and Ballistic Limit from these firings.

Section II - Effect of Temperature of Gun on Yaw*

To obtain data with respect to the effect of the temperature of a gun on the yaw of a bullet, one of the caliber .50 barrels having a twist of rifling of one turn in 12" was heated electrically to a temperature of 300° C at the middle and 170° C at the breech. Four types of bullets were fired: the Service M1 Ball and three modifications of the M1 A.P. bullet as shown on the attached Drawings Nos. 2476-A, -B and -C; the contour of the M1 Ball is similar to that of the M1 A P. and the weights are equal. The M1 Ball bullet and the 2476-C bullet (3 wide cannelures) were fired at 2900 f/s and 2500 f/s whereas the other modified bullets were fired only at 2500 f/s. The firings were carried out with the gun heated and with the gun at room temperature. For the first 39 rounds, 6 yaw cards were placed at 5 foot intervals from 10' in front of the muzzle to 35'; for the remaining rounds either two or three cards were used. The yaws and the orientations were measured on all rounds and are given in Table V at the end of this report.

* The idea of firing from a hot gun arose from a statement by Mr. Coudon of the Small Arms Section to the effect that experience had shown that a new Caliber .50 Machine Gun fired erratically after a burst of 500 rds. but, when cooled to normal temperature, the same gun regained its accuracy.

Two Orientation vs Range Charts (Nos. 5 and 6) were drawn up for Rds. 1 and 6, M1 Ball fired in a hot gun at 2500 f/s and 2900 f/s respectively. The observed slopes (φ') were found to be .085π and .087π; the theoretical slope calculated from the Moments of Inertia and the twist of rifling is .086π. This agreement between the observed and computed slopes is proof that the bullet does not slip in the bore.

An examination of Table V reveals some rather surprising results. The first round fired in this test (the gun had previously been proof-fired about five rounds) gave, with M1 Ball Ammunition at service velocity, a maximum yaw of 23°.* Of the first 10 rounds, of which five were fired at service velocity and five at 2900 f/s, 5 rounds had yaws greater than 5°.

The percent of yaws greater than 5° obtained during the entire test were plotted against the round number on Plot No. 7.

Plot No. 7 shows quite clearly that the curve representing the yaws greater than 5° against the round number is of a U-shape with a very steep negative slope for the early rounds and a gradual positive slope for the later rounds. The word gradual is used only in a comparative sense because the increase in yaw for rounds fired can hardly be called gradual when 9 out of 12 rounds fired have yaws greater than 10° in a gun fired less than 160 rounds, which actually is the case for the M1 firing at 2900 f/s in a hot gun. For the M1 projectile fired at 2500 f/s, all of the five rounds have yaws greater than 10° at about 1200 rounds when fired in a hot gun. The undercut bullet 2476-C is more accurate since none of the rounds had a yaw as great as 10° although 3 out of 10 rounds had yaws greater than 5°. Plot #8 shows the results obtained with the undercut Ball bullets. The erratic results obtained in the firing of the first few rounds were probably caused by the rough finish of the bore due to its newness.

After the firings in the 1 in 12" gun were completed, a similar test was run in a gun having a twist of 1 in 14-1/2". Ten rounds of M1 Ball were fired in a hot gun at 2500 f/s for yaw, 10 rounds at 2900 f/s and 200 rounds in a hot gun at 2500 f/s without yaw cards. This sequence of firing was repeated five times with the additional firing of several rounds of M1 Tracer and Modified M1 Tracer (2601-C) at each velocity. The percentage of rounds having yaws greater than 5° were plotted against the round number on Plot No. 9. There does not appear to be a great deal of difference between the two guns when firing M1 ball

* It should be noted that the yaws were measured during the first two of three periods of yaw; at a range of 100 yards or more the yaws will be considerably damped out and their effect on penetration will surely be negligible, provided the accuracy of the weapon is sufficient to enable the bullet to hit the target.

Ammunition; neither gives satisfactory results. Of the tracer bullets fired, only one round of 18 fired had a yaw greater than 5°. The tracer bullet differs from the M1 Ball in that it has no boat-tail and therefore has a much larger bearing surface.

In view of the very promising results obtained with the Tracer Bullet a more thorough test was made, firing twenty rounds of each of 5 types of bullets, all from a hot gun at 2900 f/s velocity. The per cent of rounds having yaws greater than 5° are given in the tabulation below:

Bullet	% of Rds. Having Yaws > 5°
Standard M1 Tracer	5
" " " Mod.#1 (2601-C)	10
" " " Mod.#2 (2601-D)	0
Standard M1 Ball	27.8 (18 rds.*)
" " " Mod.#1 (2476-A)	75

It is obvious, from an examination of these results, that the flat base bullet is superior, at least as far as initial yaw is concerned. The advantage of the boat-tail is hardly significant at velocities above that of sound; the decided superiority of the flat-base bullet in accuracy certainly compensates for the slight increase in air resistance of the bullet.

The M1 Tracer, Modif. #1 (2601-C), is cut down to .500" diameter at a point .40" from the base. The cartridge case was crimped at this point, which results in the bullet seating forward by .385". This is essentially the bullet designed by Colonel Zornig (Drawing #B129,807) and referred to in the 1st Ind. O.O. 472.54/4631. It did not result in any improvement in accuracy over the Standard Tracer but in an old gun, the lands of which have been eroded at the breech, increasing the seating might be desirable in order to have the bullet in contact with the lands before firing and thus be oriented properly. The over-all dimensions of cartridge and bullet is increased, making it impossible to fire this round in a present type belt-loaded Cal. .50

* Two rounds went through one hole; yaws could not be read.

machine gun. However, a barrel with a modified throat contour to give a similar effect of increased original bearing length without the use of a longer cartridge has been received.

In order to test the Tracer bullets for slippage, a round of each type was fired from a 1 in 15" gun for yaw and orientation. Plots Nos. 10-12 show the orientation vs distance from the muzzle for the three bullets. A comparison of the observed and computed values of φ' is given below:

			φ'
Computed (from moments of inertia)			$.072\pi$
Observed - MI Tracer			$.071\pi$
"	"	Mod. No. 1	$.072\pi$
"	"	Mod. No. 2	$.073\pi$

The close agreement between observed and calculated values shows that the bullets gain full spin in the bore. Since they have smaller initial yaws, they are undoubtedly more accurate at longer ranges than the Ball M1.

Conclusions

The large yaws obtained in the firing of the Caliber .50 M1 bullet in a hot new gun, and the fact that the gun will almost always be hot under service conditions, make a discontinuance of the test seem advisable. There is no apparent reason for choosing the best of a number of pitches of rifling from the point of view of accuracy life when a new gun gives such poor results.

It appears that a better bullet should be developed before an attempt is made to decide upon the pitch of rifling or to raise the velocity. Some of the results reported in this test should be suggestive in this connection.

In view of the small effect of yaw on armor penetration, the yaw is important, only as one of the determinants of the accuracy, since the bullet will be inaccurate due to its yaw before it will decrease significantly in penetrative power. It is not necessary, therefore, to measure yaw or

armor penetration in deciding on the optimum pitch of rifling; the accuracy life and drop in velocity with the age of the gun are sufficient.

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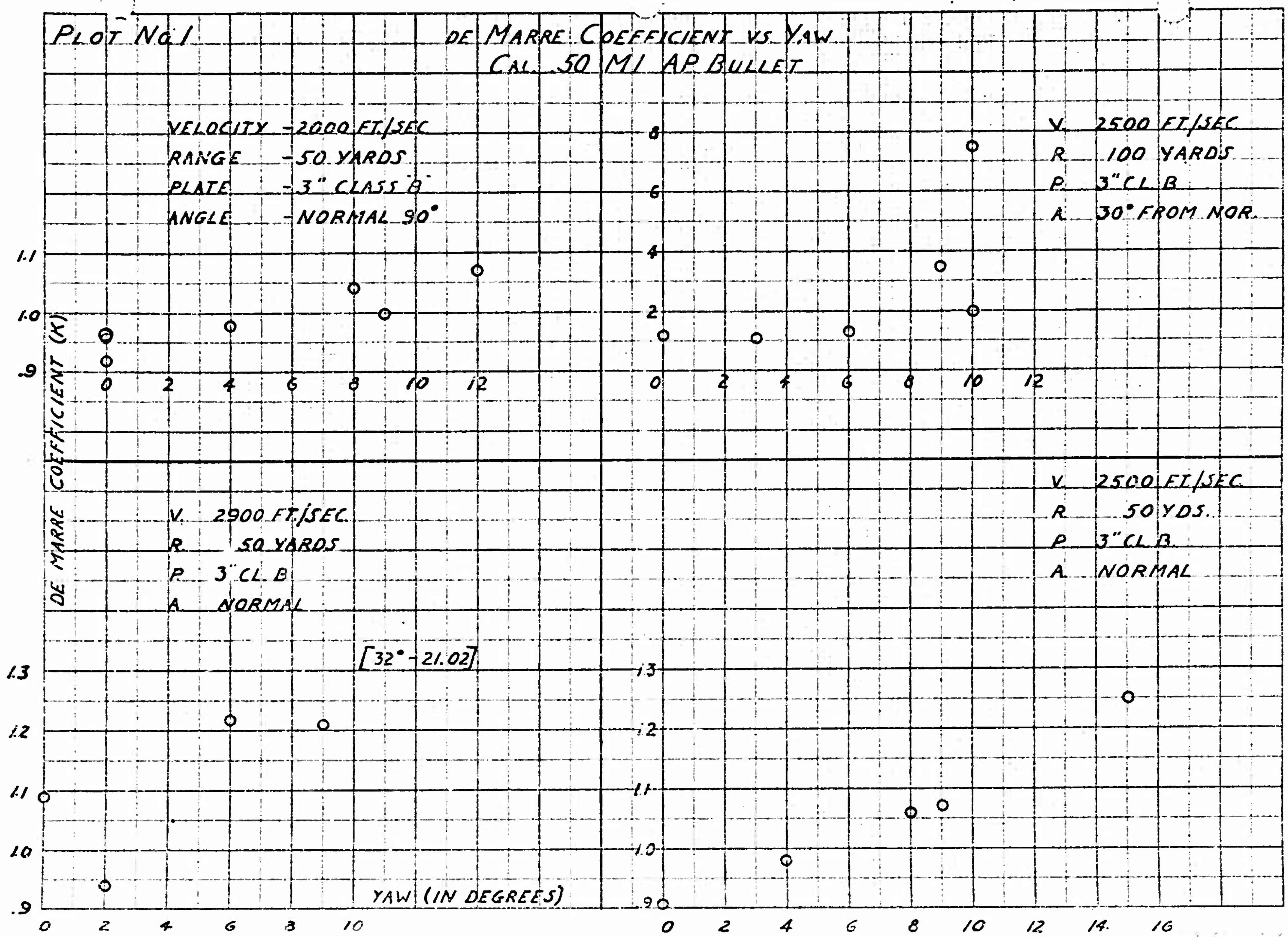
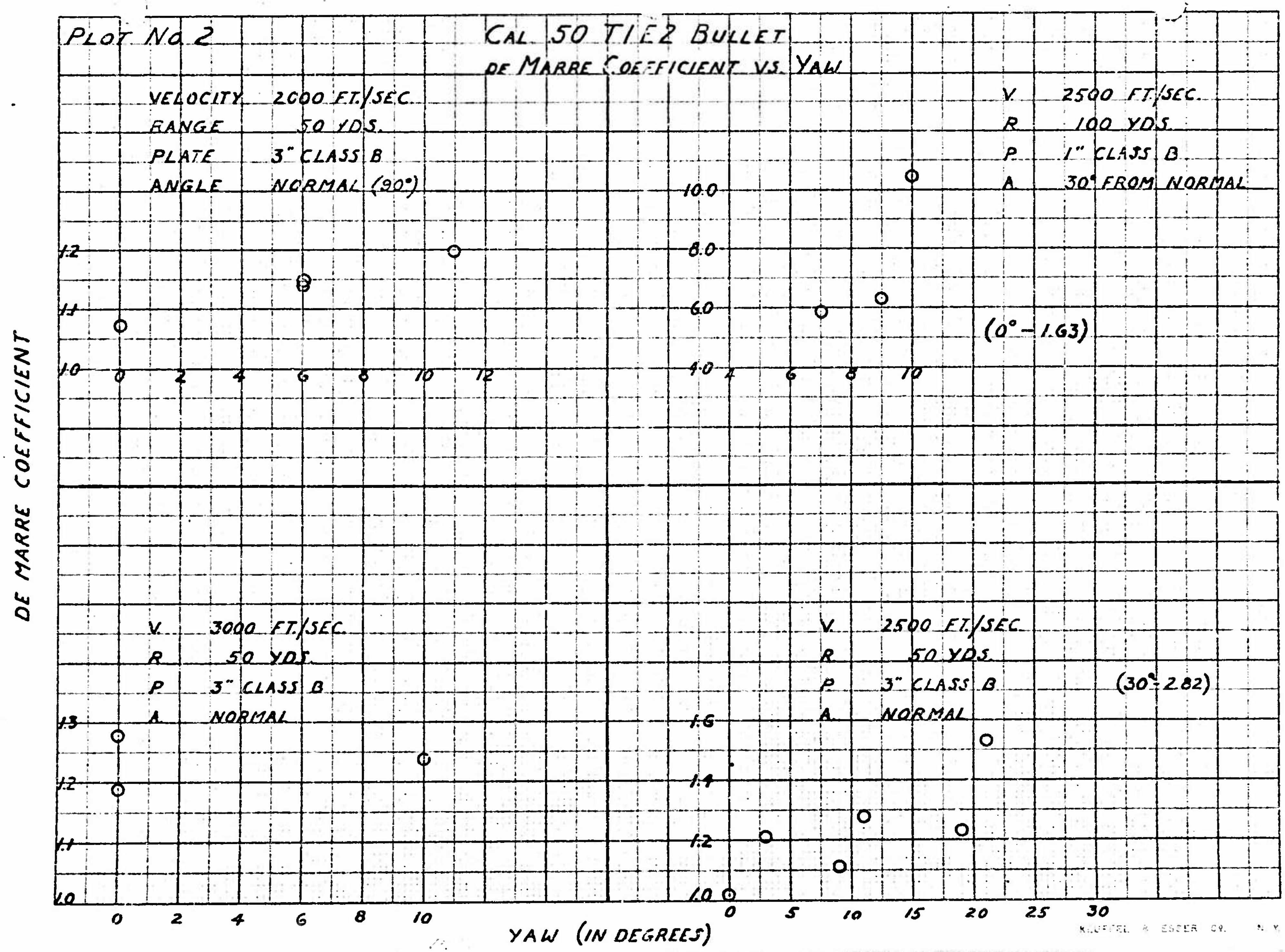
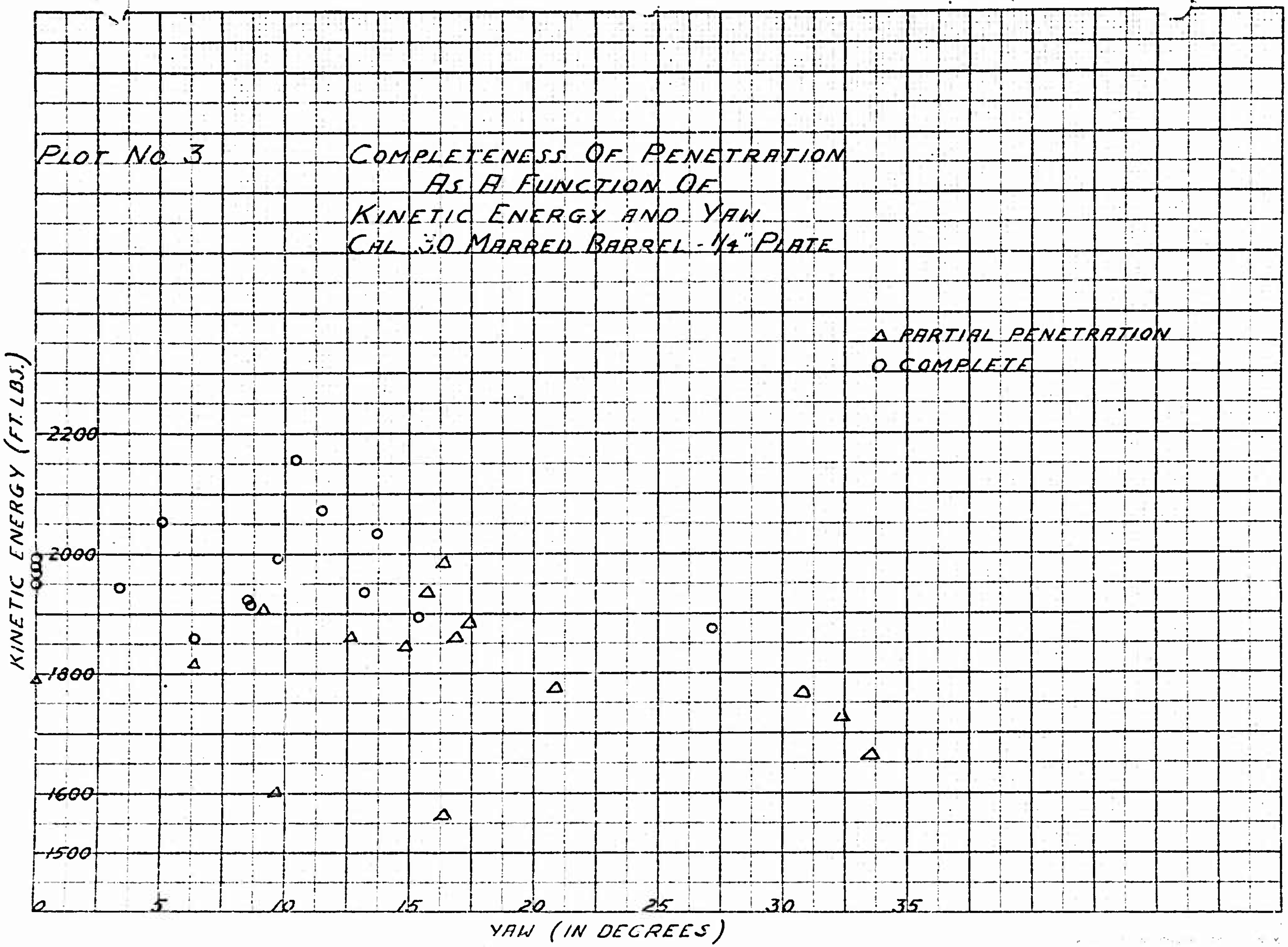
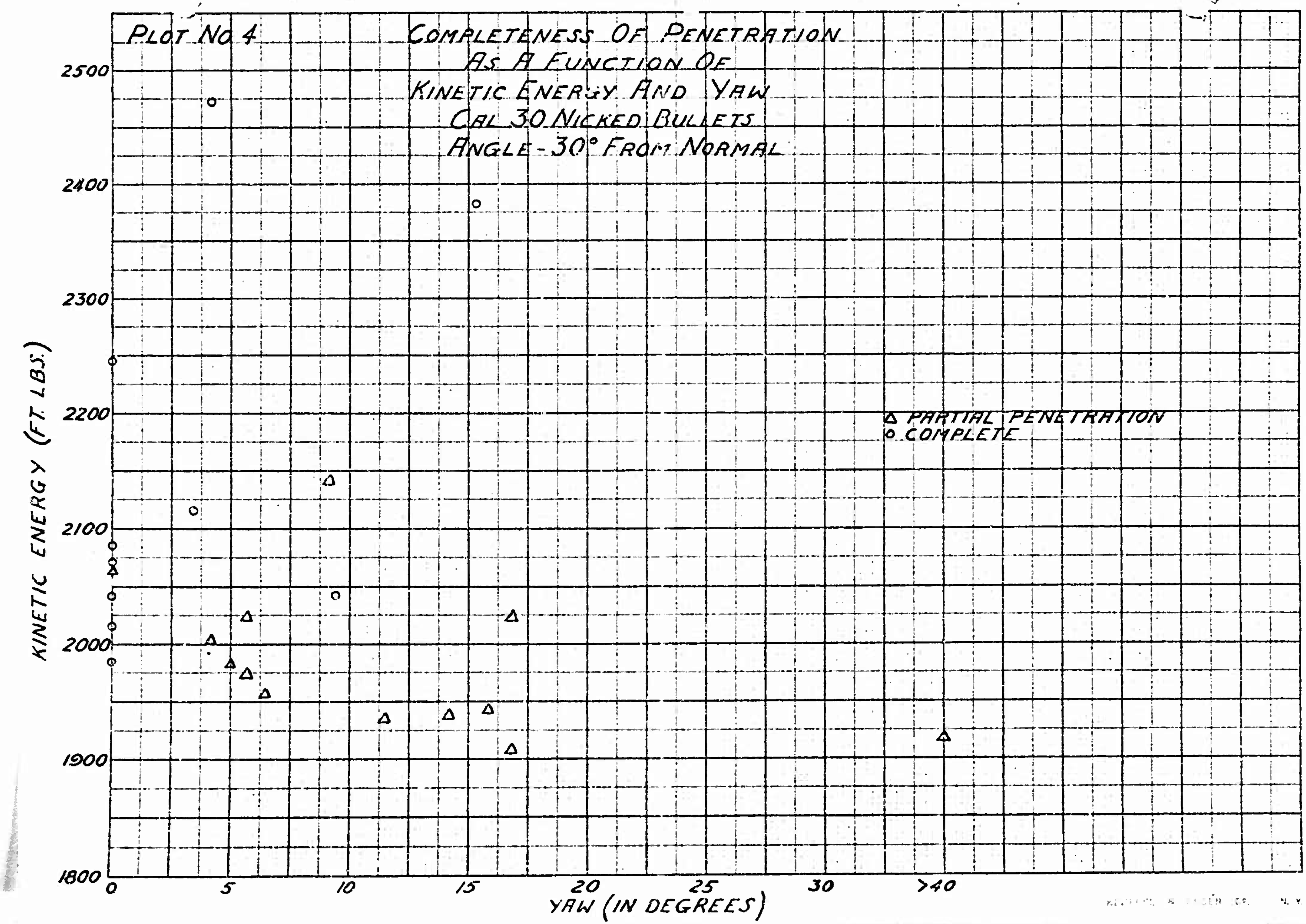
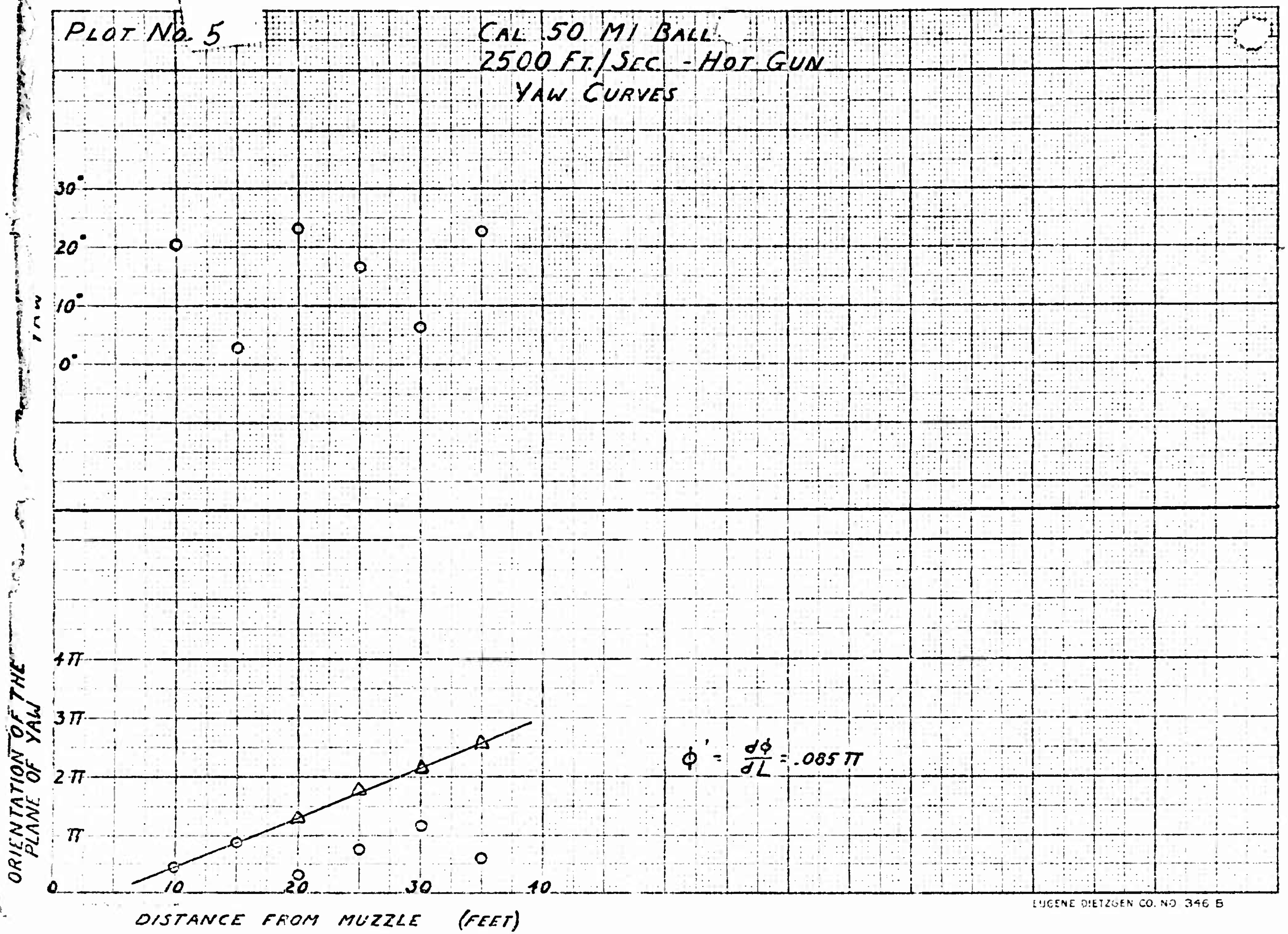

PLOT No. 1
DE MARRE COEFFICIENT VS. YAW
CAL. .50 M1 AP BULLET
VELOCITY - 2000 FT./SEC.
RANGE - 50 YARDS
PLATE - 3" CLASS B
ANGLE - NORMAL 90°
V. 2500 FT./SEC.
R. 100 YARDS
P. 3" CL. B
A. 30° FROM NOR.
V. 2900 FT./SEC.
R. 50 YARDS
P. 3" CL. B
A. NORMAL
V. 2500 FT./SEC.
R. 50 YDS.
P. 3" CL. B
A. NORMAL
[32° - 21.02]
DE MARRE COEFFICIENT (K)
YAW (IN DEGREES)


PLOT NO. 2
CAL. 50 T1E2 BULLET
DE MARRE COEFFICIENT VS. YAW
VELOCITY 2000 FT./SEC.
RANGE 50 YDS.
PLATE 3" CLASS B
ANGLE NORMAL (90°)
V 2500 FT./SEC.
R 100 YDS.
P 1" CLASS B
A 30° FROM NORMAL
(0° – 1.63)
V 3000 FT./SEC.
R 50 YDS.
P 3" CLASS B
A NORMAL
V 2500 FT./SEC.
R 50 YDS.
P 3" CLASS B
A NORMAL
(30° – 2.82)
1.0
1.1
1.2
1.3
0
2
4
6
8
10
12
4.0
6.0
8.0
10.0
1.6
1.4
1.2
1.0
5
15
20
25
30
DE MARRE COEFFICIENT
YAW (IN DEGREES)
KEUFFEL & ESSER CO. N.Y.

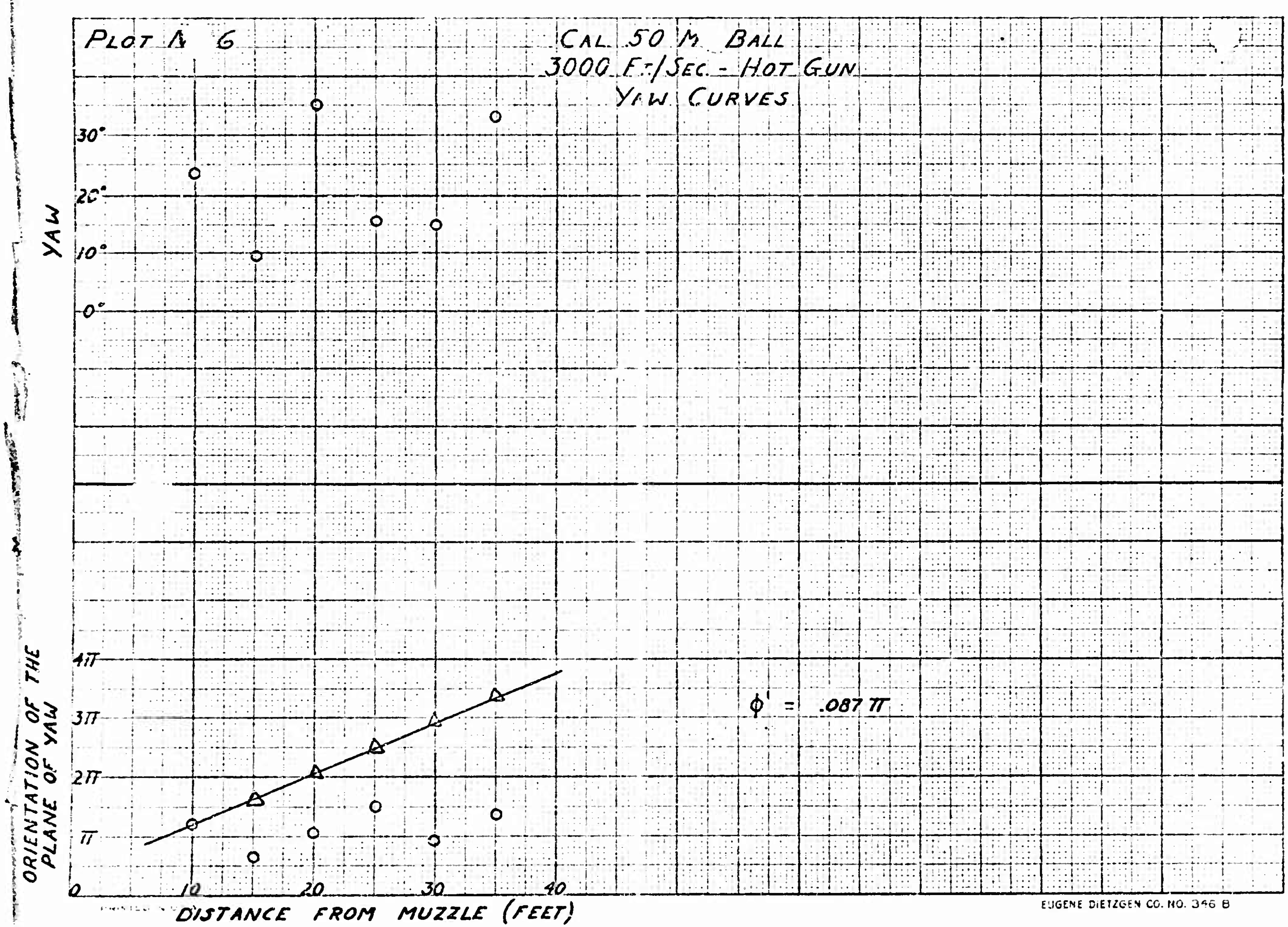

PLOT NO. 3
COMPLETENESS OF PENETRATION
AS A FUNCTION OF
KINETIC ENERGY AND YAW
CAL .30 MARRED BARREL - 1/4" PLATE
Δ PARTIAL PENETRATION
O COMPLETE
KINETIC ENERGY (FT. LBS.)
2200
2000
1800
1600
1500
0
5
10
15
20
25
30
35
YAW (IN DEGREES)



PLOT NO 4
COMPLETENESS OF PENETRATION
AS A FUNCTION OF
KINETIC ENERGY AND YAW
CAL 30 NICKED BULLETS
ANGLE - 30° FROM NORMAL
△ PARTIAL PENETRATION
○ COMPLETE
KINETIC ENERGY (FT. LBS.)
2500
2400
2300
2200
2100
2000
1900
1800
0
5
10
15
20
25
30
>40
YAW (IN DEGREES)

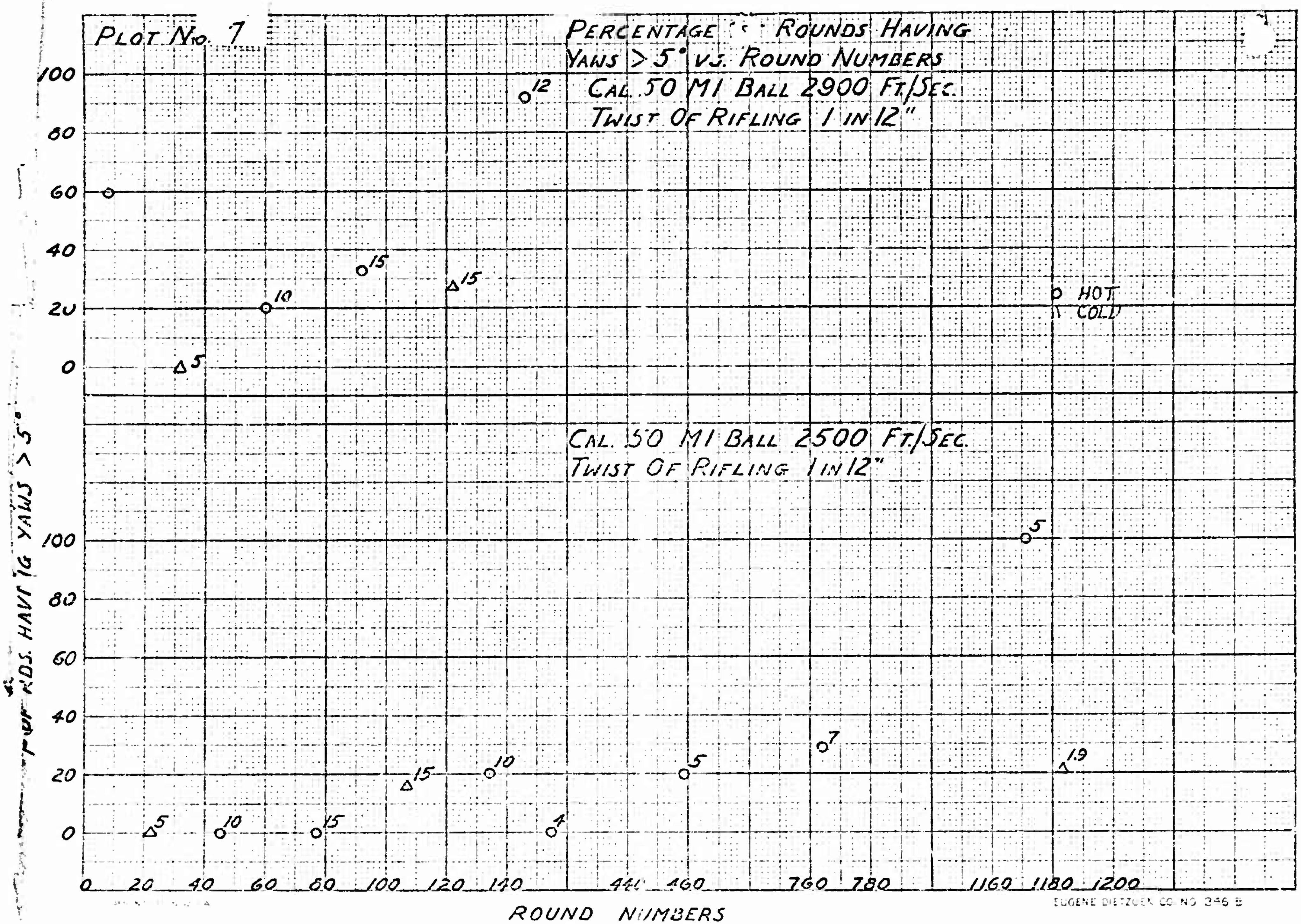


EUGENE DIETZGEN CO. NO. 346 B

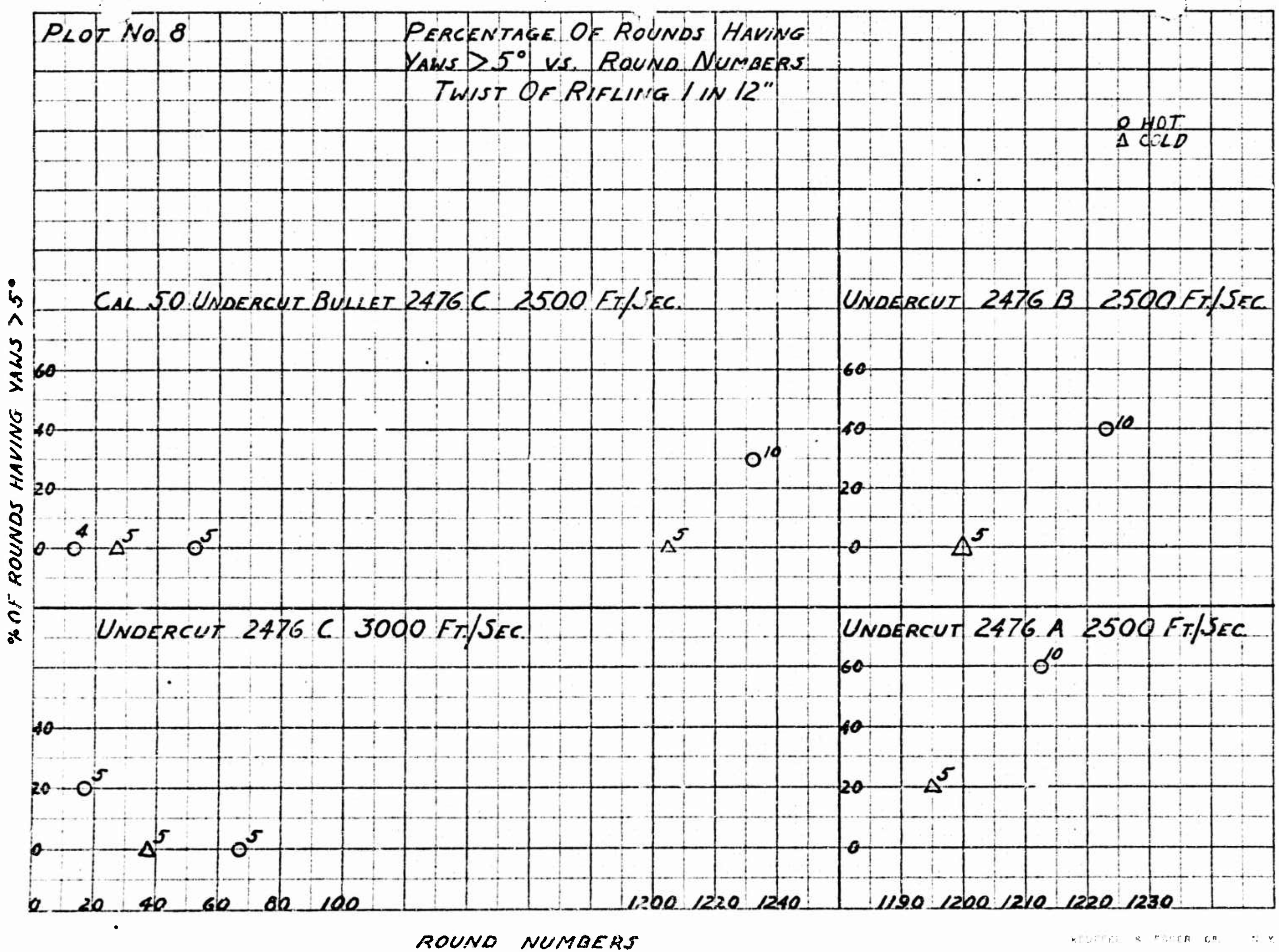


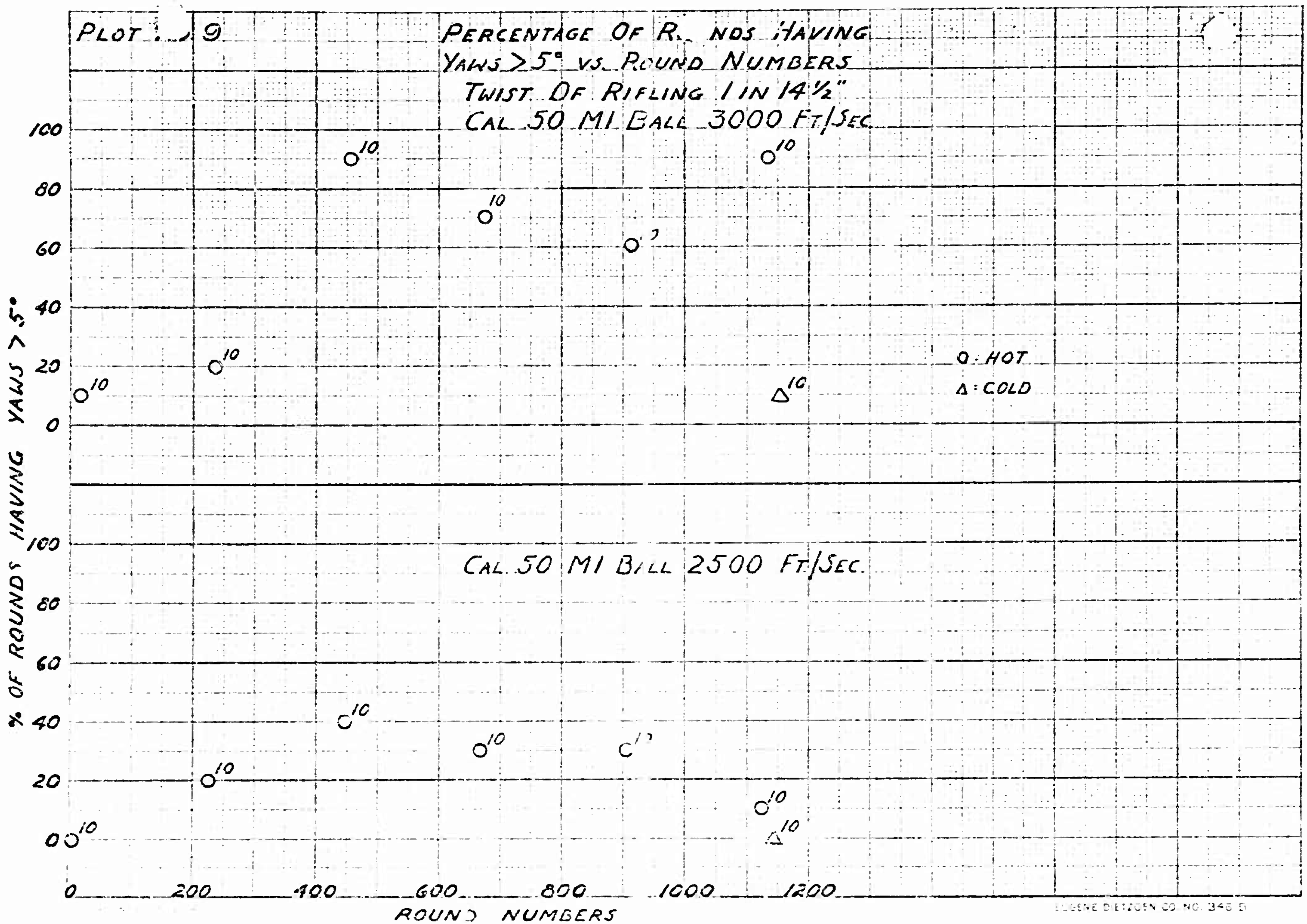
PLOT No 6
CAL .50 M. BALL
3000 FT/SEC. - HOT GUN
YAW CURVES
YAW
30°
20°
10°
0°
ORIENTATION OF THE PLANE OF YAW
4π
3π
2π
π
0
10
20
30
40
DISTANCE FROM MUZZLE (FEET)
φ' = .087 π
EUGENE DIETZGEN CO. NO. 346 B

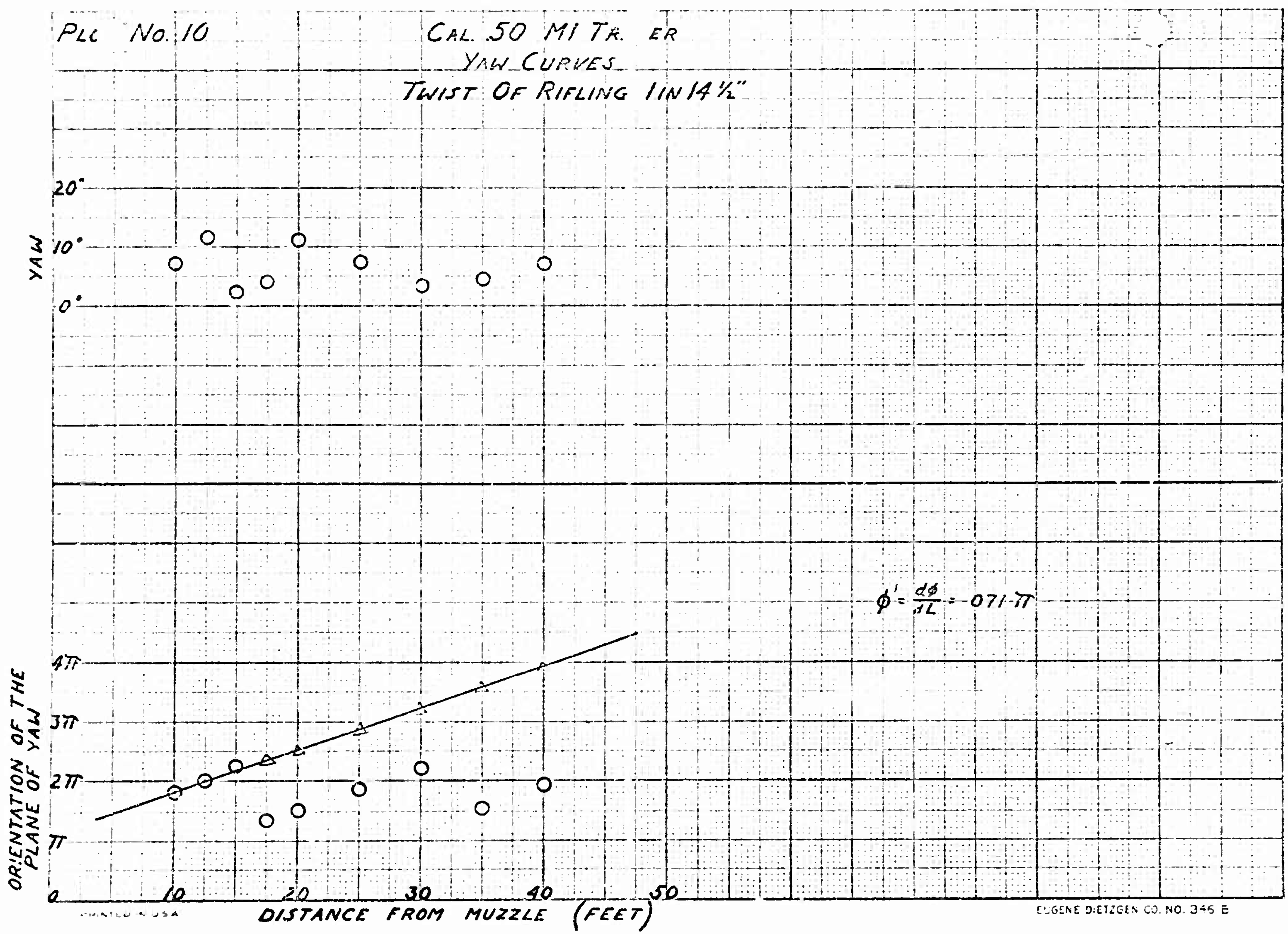
Plot No. 7



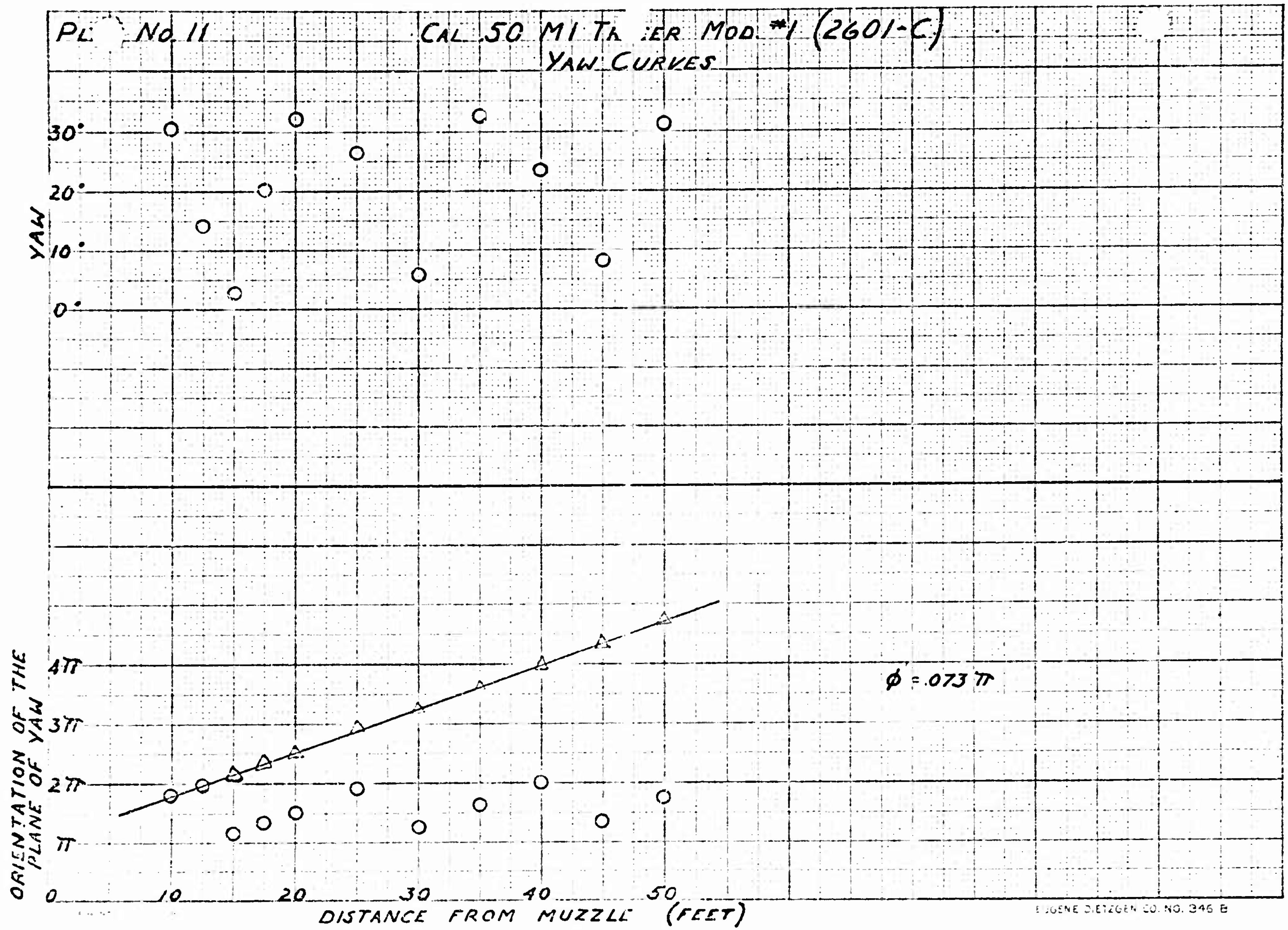
Percentage of Rounds Having Yaws > 5° vs. Round Numbers
Cal. 50 M1 Ball 2900 Ft/Sec.
Twist Of Rifling 1 in 12"
Cal. 50 M1 Ball 2500 Ft/Sec.
Twist Of Rifling 1 in 12"
o Hot
Δ Cold
% of Rds. Having Yaws > 5°
Round Numbers
0 20 40 60 80 100 120 140 440 460 760 780 1160 1180 1200
100 80 60 40 20 0

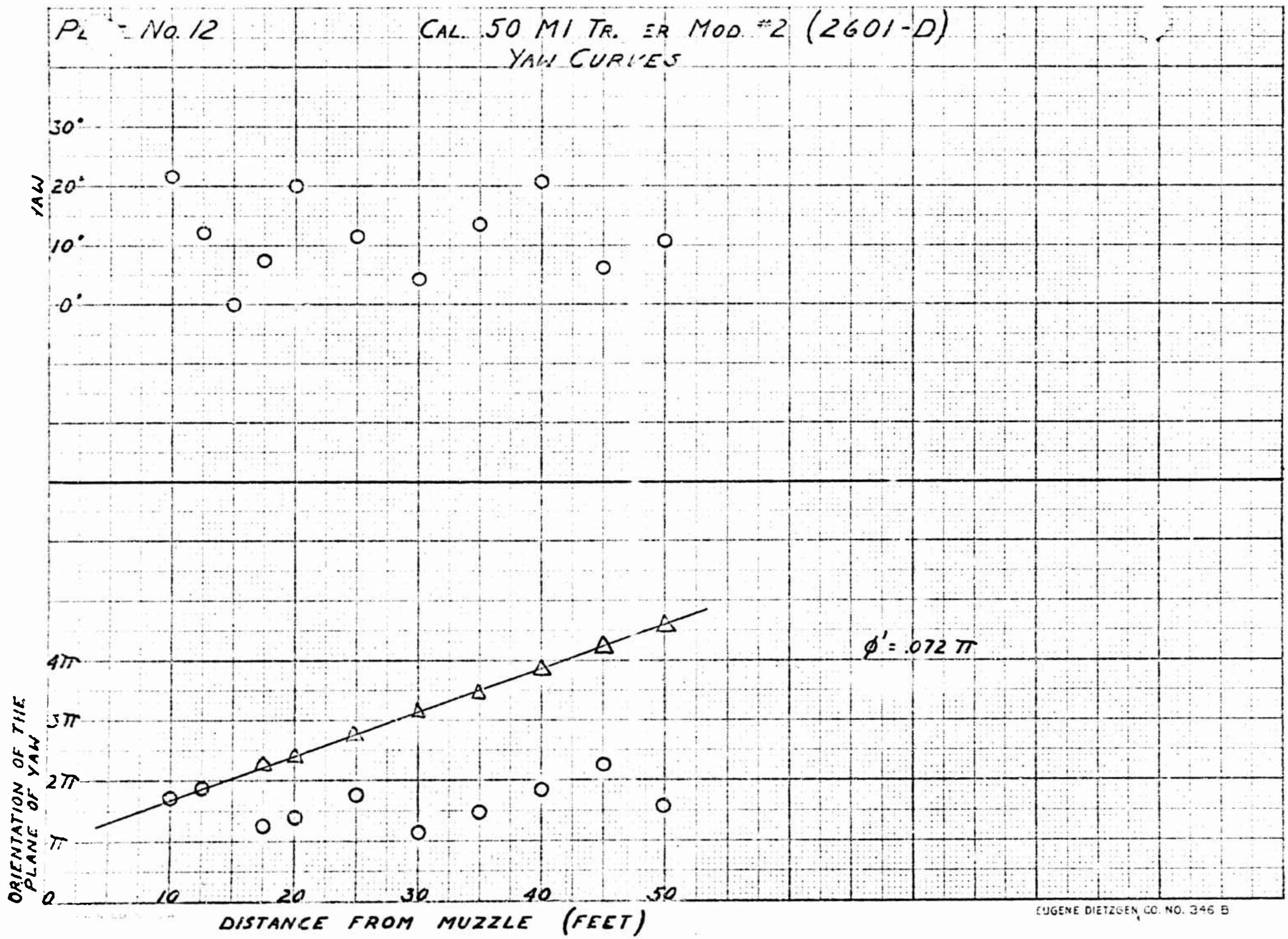

PLOT NO. 8
PERCENTAGE OF ROUNDS HAVING YAWS > 5° VS. ROUND NUMBERS
TWIST OF RIFLING 1 IN 12"
O HOT
Δ COLD
CAL .50 UNDERCUT BULLET 2476 C 2500 FT./SEC.
UNDERCUT 2476 B 2500 FT./SEC.
UNDERCUT 2476 C 3000 FT./SEC.
UNDERCUT 2476 A 2500 FT./SEC.
% OF ROUNDS HAVING YAWS > 5°
ROUND NUMBERS
0 20 40 60 80 100
1200 1220 1240
1190 1200 1210 1220 1230
0 20 40 60


PLOT ... 9
PERCENTAGE OF R.. NDS HAVING YAWS > 5° VS. ROUND NUMBERS
TWIST OF RIFLING 1 IN 14½"
CAL. 50 M1 BALL 3000 FT./SEC.
CAL. 50 M1 BALL 2500 FT./SEC.
O: HOT
Δ: COLD
% OF ROUNDS HAVING YAWS > 5°
ROUND NUMBERS
0
20
40
60
80
100
200
400
600
800
1000
1200
EUGENE DIETZGEN CO. NO. 346 D



PLC No. 10
CAL .50 M1 TR ER
YAW CURVES
TWIST OF RIFLING 1 IN 14½"
YAW
20°
10°
0°
$\phi' = \frac{d\phi}{dL} = .071\pi$
ORIENTATION OF THE PLANE OF YAW
4π
3π
2π
π
0
10
20
30
40
50
DISTANCE FROM MUZZLE (FEET)
EUGENE DIETZGEN CO. NO. 346 B


PL No. 11
CAL .50 M1 TR ER MOD #1 (2601-C)
YAW CURVES
YAW
30°
20°
10°
0°
ORIENTATION OF THE PLANE OF YAW
4π
3π
2π
π
0
10
20
30
40
50
DISTANCE FROM MUZZLE (FEET)
φ = .073 π
EUGENE DIETZGEN CO. NO. 346 B



PL - No. 12
CAL. .50 M1 TR. ER MOD. #2 (2601-D)
YAW CURVES
YAW
30°
20°
10°
0°
ORIENTATION OF THE PLANE OF YAW
4π
3π
2π
π
0
10
20
30
40
50
DISTANCE FROM MUZZLE (FEET)
φ' = .072 π
EUGENE DIETZGEN CO. NO. 346 B

TABLE I

Bullet : Cal. .50 Armor Piercing, M1
Plate : Navy Class "B", Thickness 3"
Range to Plate: 100 yards
Angle of Plate: 90° (Normal)

Rd. No.	Twist of Rifling	Striking Velocity	Measured Penetration (Along axis of bullet)	Penetration (Normal to Plate)	Angle of Yaw
1	12"	2443	1.64"	1.62	0°
2		2427	1.61	1.59	0
3		2372	1.53	1.532	0
4		2390			
5		2374	1.54	1.53	
6	13"	2456	1.60	1.58	
7		2415	1.63	1.63	
8		2398	1.49	1.46	
9		2352	1.52	1.50	-
10		-	1.52	1.51	-
11		2358	1.47	1.46	
12		2390			
13		2421	1.62	1.61	-
14	14"	2354	1.56	1.52	0
15		2406	1.56	1.52	-
16		2352	1.46	1.43	0
17		2371	1.54	1.51	0
18		2341	1.49	1.49	0
24	15"	2410	1.55	1.55	-
25		2385			-
26		2445	1.58	1.57	0
27		2402	1.52	1.52	0
28		2386	1.49	1.46	-
57	12"				-
58		-	1.18	1.16	
59		1866	1.10	1.09	
60		1931			
61		1936			
51	13"	1916			
52		1888	1.11	1.10	-
52		-	1.23	1.23	
54		1960			
55		1966	1.24	1.21	
56		1932	1.13	1.12	

TABLE I (CONT'D)

Bullet : Cal. .50 Armor Piercing, M1
Plate : Navy Class "B", Thickness 3"
Range to Plate : 100 yards
Angle of Plate : 90° (Normal)

Rd. No.	Twist of Rifling	Striking Velocity	Measured Penetration (Along axis of Bullet)	Penetration (Normal to Plate)	Angle of Yaw
72	14"	1903			-
73		1888	1.11"	1.10	
74		-	1.16	1.06	
75		-	1.08	1.08	
76		1933			
77		1918	1.15	1.13	
78		1934	1.18	1.17	
84	15"	1946	1.14	1.14	
85		-	1.10	1.10	
86		1818	1.21	1.19	
87		1947	1.19	1.19	
88		2046			
89		2041			

Bullet : Cal. .50 Armor Piercing, M1, Nicked

Rd. No.	Twist of Rifling	Striking Velocity	Measured Penetration (Along axis of Bullet)	Penetration (Normal to Plate)	Angle of Yaw
90	15"	2032	1.26	1.18	3.7
91		2031	1.26	1.18	-
92		2018	1.21	1.16	
93		1978	1.16	1.12	0
94		2014	1.19	1.12	9.4
95		2017	1.15	1.07	8.1
96		1987	1.19	1.06	12.0
97		2000	1.19	1.14	-
98		est. 2000	1.12	1.04	9.4
99		"	1.51	1.50	
100		"	1.17	1.15	
101		"	1.23	1.18	
102		"	1.22	1.16	
103		"			
104		"	1.22	1.17	
105					
106		"	1.14	1.11	
107		"	1.12	1.12	
108		"	1.18	1.14	
126		est. 2500	1.66	1.63	-
127		"	1.61	1.59	

TABLE I (CONT'D)

Bullet : Cal. .50 Armor Piercing, M1
Plate : Navy Class "B", Thickness 3"
Range to Plate : 100 yards
Angle of Plate : 90° (Normal)

Rd. No.	Twist of Rifling	Striking Velocity	Measured Penetration (Along axis of Bullet)	Penetration (Normal to Plate)	Angle of Yaw
34	12"	2411	1.35"	1.33	0
35		2431	1.36	1.35	-
36		2446	1.41	1.40	
37		2456	1.38	1.38	
38		2461	1.38	1.36	
39		2405	1.37	1.34	
40	13"	2396	1.31	1.31	0
41		3444	1.33	1.32	-
42		2441	1.37	1.36	
43		2388	1.32	1.32	
44		2430	1.35	1.34	
45		2427	1.47	1.46	
19	14"	2358	1.33	1.30	0
20		2367	1.30	1.29	0
21		2399			-
22		2397			-
23		2392	1.30	1.29	0
29	15"	2480	1.42	1.42	-
30		2424	1.34	1.33-	0
31		2432	1.40	1.38	0
32		-	1.43	1.43	-
33		2445	1.38	1.38	-
62	12"	1944			-
63		1938	0.96	0.91	
64		1959			
65		2020	0.95	0.94	
66		1951			
46	13"	2027	0.95	0.95	-
47		1941	0.92	0.91	
48		1914	0.90	0.89	
49		-	0.94	0.93	
50		1961			

TABLE I (CONT'D)

Bullet : Cal. .50 Armor Piercing, M1
Plate : Navy Class "B", Thickness 3"
Range to Plate : 100 yards
Angle of Plate : 90° (Normal)

Rd. No.	Twist of Rifling	Striking Velocity	Measured Penetration (Along axis of Bullet)	Penetration (Normal to Plate)	Angle of Yaw
67	14"	1933	0.93"	0.93"	-
68		1896	0.93	0.92	
69		1909			
70		1968	1.12	1.09	
71		-	0.88	0.87	
79	15"	1959	0.96	0.96	-
80		1964	0.96	0.95	
81		1955	0.94	0.93	
82		1967			
83		1963			

Bullet : Cal. .50 Armor Piercing, T2-E1, Nicked

Rd. No.	Twist of Rifling	Striking Velocity	Measured Penetration (Along axis of Bullet)	Penetration (Normal to Plate)	Angle of Yaw
109	15"	est.2000	0.96	0.94	-
110		"			9.3
111		"	0.92	0.88	8.0
112		"	0.92	0.84	10.5
113		"	0.90	0.80	13.4
114		"	0.90	0.76	16.6
115		"	0.89	0.84	6.7
116		"	0.92	0.88	5.9
117		"			7.0
118		"	0.84	0.75	15.4
119		"	0.97	0.87	11.6
120		"	0.88	0.81	9.5
121		"	0.88	0.76	15.3
122		"			15.7
123		"	0.94	0.84	10.5
124		est. 2500	1.30	1.21	10.0
125		"	1.19	1.14	7.0
128		"	1.17	1.08	6.4
129		"	1.16	1.06	13.9
130		"	1.25	1.17	6.4
131		"	1.22	1.03	9.9

TABLE I (CONT'D)

Bullet : Cal. .50 Armor Piercing, M1
Plate : Navy Class "B", Thickness 3"
Range to Plate : 50 yards
Angle of Plate : 90° (Normal)

Rd. No.	Twist of Rifling	Striking Velocity	Measured Penetration (Along axis of Bullet)	Penetration (Normal to Plate)	Angle of Yaw
132	15"	-	1.38"	0.96	18.4
133		2442	1.50	1.372	9.4
134		2451	1.51	1.48	-
135		2457	1.53	1.40	8.5
136		2443	1.54	1.47	4.4
137		2418	1.46	1.21	14.7

Bullet : Cal. .50 Armor Piercing, T2-E1, Nicked
Range to Plate : 50 yards

138		2400	1.21	1.11	19
139		2423			2
140		2415			2
141		2403	1.30	1.11	11
142		2392	1.23	1.12	3
143		2409	1.53	1.15	21
144		2431	1.27	1.22	9
145		2468	1.16	0.63	30
146		2015	0.95	0.92	6
147		2059	0.97	0.93	6
148		2034	0.95	0.89	11
149	15"	2976	1.67	1.63	
150		2965	1.59	1.54	
151		2916	1.61	1.60	
152		2931	1.64	1.64	
154		2979	1.66	1.64	

Bullet : Caliber .50 Armor Piercing, M1, Nicked

161	15"	-	1.79	1.57	9
162		-	1.68	1.51	6
163		-	0.80	0.14	32
164		2909	1.94	1.91	2

TABLE I (CONT'D)

Bullet : Cal. .50 Armor Piercing, M1
Plate : Navy Class "B", Thickness 3"
Range to Plate : 100 yards
Angle of Plate : 30° from Normal

Rd. No.	Twist of Rifling	Striking Velocity	Measured Penetration (Along axis of bullet)	Penetration (Normal to Plate)	Angle of Yaw
165	15"	1990	1.24	0.75	
166		1978	Gore in plate		
167		1972	Core in plate		
168		1987	Core in plate		
169		2421	1.71	1.38	
170		2435	1.58	1.28	
171		2411	1.83	1.42	
172		2390	Core in plate		
173		2420	1.84	1.41	
174		2425	Core in plate		
175		2418	1.79	1.27	

Bullet : Cal. .50 Armor Piercing, M1, Nicked
Plate : Navy Class "B", Thickness 1"
Angle of Plate : 30° from Normal

Rd. No.	Twist of Rifling	Striking Velocity	Measured Penetration (Along axis of bullet)	Penetration (Normal to Plate)	Angle of Yaw
181	15"	2422	1.21		
182		2390	1.27		
183		2363	1.15		
184		2361	1.14		
185		2411	1.30	1.08	
186		2405	1.48	1.34	
187			1.20	0.33	
188			1.00	0.73	
189		2366	1.20	0.54	

Bullet : Cal. .50 Armor Piercing, T2-E1
Plate : Navy Class "B", Thickness 3"
Range to Plate : 50 yards
Angle of Plate : 90° (Normal)

Rd. No.	Twist of Rifling	Striking Velocity	Measured Penetration (Along axis of bullet)	Penetration (Normal to Plate)	Angle of Yaw
153	15"	2969	1.41	1.41	
155		2951	1.37	1.37	
156		2977	1.69	1.69	
157		2966	1.35	1.35	
158		2957	1.34	1.33	

TABLE I (CONT'D)

Bullet : Cal. .50 Armor Piercing, T2-E1
Plate : Navy Class "B", Thickness 3"
Range to Plate : 50 yards
Angle of Plate : 90° (Normal)

Rd. No.	Twist of Rifling	Striking Velocity	Measured Penetration (Along axis of Bullet)	Penetration (Normal to Plate)	Angle of Yaw
159	15"	-	1.29	1.26	
160		2903	1.60	1.44	

Bullet : Cal. .50 Armor Piercing, T2-E1
Range to Plate : 100 yards
Angle of Plate : 30° from Normal.

Rd. No.	Twist of Rifling	Striking Velocity	Measured Penetration (Along axis of Bullet)	Penetration (Normal to Plate)	Angle of Yaw
176	15"	2434	1.74	1.09	
177		2425	1.78	1.10	
178		2425	1.82	1.02	
179		2393	1.63	1.13	
180		2437	1.76	1.27	

Bullet : Cal. .50 Armor Piercing, T2-E1, Nicked
Plate : Navy Class "B", thickness 1"
Angle of Plate : 30° from Normal

Rd. No.	Twist of Rifling	Striking Velocity	Measured Penetration (Along axis of Bullet)	Penetration (Normal to Plate)	Angle of Yaw
190	15"	-	0.86	0.36	
191		2406	0.90	0.34	
192		2356	0.86		
193		2390	0.80	0.30	
194		2373	0.75	0.21	
195		2385	0.85		

TABLE II - DE MARRE COEFFICIENT

Bullet - Cal. .50 MI A.P.

Normal Impact

Twist	Velocity	3000 f/s No. Rds.	k	2500 f/s No. Rds.	k	2000 f/s No. Rds.	k
12"				4	.90	1	.91
13"				6	.91	3	.92
14"				4	.92	3	.96
15"		5	1.09	4	.91	3	.89

30° From Normal Impact

Twist	Velocity	3000 f/s No. Rds.	k	2500 f/s No. Rds.	k	2000 f/s No. Rds.	k
15"		1	1.89	5	1.22		

Nicked Bullets - Normal Impact

Twist		3000 f/s Yaw	k	2500 f/s Yaw	k	2000 f/s Yaw	k
15"		9°	1.21	9°	1.07	4°	.98
		6	1.22	8	1.06	0	.96
		32	21.02	4	.98	0	.96
		2	.92	15	1.25	9	1.00
						8	1.04
						12	1.07

Nicked Bullets - 30° From Normal

Twist		3000 f/s Yaw	k	2500 f/s Yaw	k	2000 f/s Yaw	k
				6°	1.36		
				3	1.07		
				10	7.47		
				10	1.98		
				9	3.48		

Table II - DE MARRE COEFFICIENT

Bullet - Cal. .50 T2E1

Twist	Velocity	3000 f/s		2500 f/s		2000 f/s	
		No. Rds.	k	No. Rds.	k	No. Rds.	k
Normal Impact							
12"				6	1.02	2	1.12
13"				6	1.01	3	1.09
14"				3	1.03	3	1.03
15"		5	1.19	4	1.01	3	1.06
30° From Normal Impact							
15"				5	1.63		
Nicked Bullets - Normal Impact							
		Yaw	k	Yaw	k	Yaw	k
15"		0°	1.28	19°	1.23	6°	1.14
		10	1.24	11	1.28	6	1.15
				3	1.21	11	1.20
				21	1.53		
				9	1.11		
				30	2.82		
Nicked Bullets - 30 From Normal							
15"				7°	5.87		
				9	6.39		
				10	10.52		

Table IV

Date 1935	Rd. No.	Striking Velocity	Yaw	Penetration	Remarks
9/10	1	1773		Partial	M1922 A.P. Bullet
	2	1773		"	Range 100 yards
	3	1774		"	
10/21	4	1943	0	"	
	5	2053	0	"	
	6	2165	0	Complete	Normal Penetration
	7	2055	0	Partial	" "
	8	2110	0	Complete	1/4" Plate
	9	2085	0	Partial	
10/22	10	2160	0	Partial	Nicked Bullets
	11	2182	0	Complete	
	12	2284		Partial	
	13	2353		Complete	Range - 50 yds.
	14	2338		Complete	Nicked Bullets
	15	2073	9.7	Partial	
	16	2049	16.4	Partial	
	17	2405	10.4	Complete	
	18	2361	11.5	Complete	Range - 50 yds.
	19	2191	0	Partial	
	20	2309	16.4	Partial	
	21	2306	0	Complete	
	22	2266	9.2	Partial	Un-nicked bullets
	23	2292	0	Complete	Marred Barrel
	24	2146	-	Partial	
	25	2213	-	Complete	
	26	2124	-	Partial	
	27	2147	-	Complete	
	28	-	0	Complete	
	29	-	0	Complete	
10/23	31	2288	3.4	Complete	
	32	2275	8.5	Complete	
	33	2183	20.9	Partial	
	34	2180	30.8	Partial	
	35	2283	13.2	Complete	
	36	2246	27.2	Complete	
	37	2299	-	Complete	
	38	2225	14.8	Partial	
	39	2114	33.6	Partial	
	40	2336	13.7	Complete	
	41	2350	5.0	Complete	
	42	2315	9.7	Complete	
	43	2259	15.3	Complete	
	44	2154	32.4	Partial	
	45	2236	6.4	Complete	
	46	2250	17.4	Partial	
	47	2235	16.8	Partial	
	48	2209	6.4	Partial	
	49	2281	15.8	Partial	
	50	2269	8.5	Complete	
	51	2333	12.6	Partial	

Table IV (cont'd)

Date 1935	Rd. No.	Striking Velocity	Yaw	Penetration	Remarks
10/31	1	2243	40	Partial	Normal Penetration
	2	2256	23.3	Partial	
	3	-	40	Partial	
	4	2351	27.7	Partial	Oblique Impact - 30°
	5	-	40	"	
	6	-	6.4	Complete	
	7	2595	4.2	Complete	
	8	2541	15.3	Complete	
	9	2369	0	Partial	
	10	2453		Complete	
	11	2475	0	Complete	
	12	2401	3.4	Complete	
	13	2412	9.2	Partial	
	14	2334	0	Complete	
	15	2367	9.2	Complete	Range - 50 yds.
	16	2347	16.8	Partial	
	17	2358	0	Complete	Oblique Impact - 30°
	18	2342	0	Complete	
	19	2380	0	Complete	Nicked Bullets
	20	2371	0	Complete	
	21	2335	4.2	Partial	
	22	2299	40	Partial	
	23	2364	0	Complete	
	24	2301	11.5	Partial	
	25	-	0	Complete	
	26	2314	14.2	Partial	
	27	-	13.2	Partial	
	28	2320	6.4	Partial	
	29	2334	5.0	Partial	
	30	2327	15.8	Partial	
	31	-	7.2	Partial	
	32	2364	5.8	Partial	
	33	2292	16.8	Partial	
	34	2323	5.7	Partial	
	35	-	13.7	Partial	

Table V

Orientation and Yaws Obtained in Firing of Hot Gun of 1 in 12" Twist

Rd. No.	Bullet	Vel. (Est)	10 ft. Orient-ation	10 ft. Yaw	15 ft. Orient-ation	15 ft. Yaw	20 ft. Orient-ation	20 ft. Yaw	25 ft. Orient-ation	25 ft. Yaw	30 ft. Orient-ation	30 ft. Yaw	35 ft. Orient-ation	35 ft. Yaw	Temp. of Barrel
1	M1 Ball	2500	83 °	20.4	156°	2.8	54 °	23.3	136 °	16.6	209°	6.5	106°	22.8	Breech 170 °C
2			152	2.8	-	0	-	0	191	4.8	-	0	-	0	Middle 300 °C
3			172	4.8	-	0	-	0	203	5.4	-	0	-	0	Muzzle 185 °C
4			-	0	-	0	-	0	-	0	-	0	-	0	
5			220	3.5	-	0	-	0	-	0	-	0	-	0	
6	"	2900	220	23.5	114	9.2	190	35	271	15.6	170	15.0	247	33	
7			178	17.6	-	0	151	19.6	225	14.5	-	0	202	19.2	
8			-	0	-	0	-	0	0	0	-	0	-	0	Heated
9			-	0	-	0	-	0	0	0	-	0	-	0	
10			255	5.4	-	0	219	6.5	300	5.4	-	0	272	4.2	
11	2476-C	2500	-	0	-	0	-	0	-	0	-	0	-	0	
12			-	0	-	0	-	0	-	0	-	0	-	0	
13			-	0	-	0	-	0	-	0	-	0	-	0	
14			-	0	-	0	-	0	-	0	-	0	-	0	
15	"	2900	-	0	-	0	-	0	-	0	-	0	-	0	Heated
16			53	6.0	-	0	29	5.4	101	4.8	-	0	-	0	
17			-	0	-	0	-	0	-	0	-	0	-	0	
18			-	0	-	0	-	0	-	0	-	0	-	0	
19			-	0	-	0	-	0	-	0	-	0	-	0	
20	M1 Ball	2500	-	0	-	0	-	0	-	0	-	0	-	0	
21			-	0	-	0	-	0	-	0	-	0	-	0	
22			-	0	-	0	-	0	-	0	-	0	-	0	Room
23			-	0	-	0	-	0	-	0	-	0	-	0	Temperature
24			-	0	-	0	-	0	-	0	-	0	-	0	
25	2476-C	"	-	0	-	0	-	0	-	0	-	0	-	0	

Table 7

Orientation and Yaws Obtained in Firing of Hot Gun of 1 in 12" Twist

Rd. No.	Bullet	Vel. (Est)	10 ft. Orientation	10 ft. Yaw	15 ft. Orientation	15 ft. Yaw	20 ft. Orientation	20 ft. Yaw	25 ft. Orientation	25 ft. Yaw	30 ft. Orientation	30 ft. Yaw	35 ft. Orientation	35 ft. Yaw	Temp. of Barrel
26	2476-C	2500	-	0.	-	0	-	0	-	0	-	0	-	0	Room Temperature
27			194	3.5	-	0	-	0	-	0	-	0	-	0	
28			-	0	-	0	-	0	-	0	-	0	-	0	
29			177	2.2	-	0	-	0	-	0	-	0	-	0	
30	M1 Ball	2900	-	0	-	0	-	0	-	0	-	0	-	0	
31			-	0	-	0	-	0	-	0	-	0	-	0	
32			-	0	-	0	-	0	-	0	-	0	-	0	
33			-	0	-	0	-	0	-	0	-	0	-	0	
34			-	0	-	0	-	0	-	0	-	0	-	0	
35	2476-C	2900	-	0	-	0	-	0	-	0	-	0	-	0	
36			-	0	-	0	-	0	-	0	-	0	-	0	
37			-	0	-	0	-	0	-	0	-	0	-	0	
38			-	0	-	0	-	0	-	0	-	0	-	0	
39			-	0	-	0	-	0	-	0	-	0	-	0	

Table V

Orientation and Yaws Obtained in Firing of Hot Gun of 1 in 12" Twist

Rd. No.	Bullet	Vel. (Est)	10 ft. Orient-ation	10 ft. Yaw	13 ft. Orient-ation	13 ft. Yaw	20 ft. Orient-ation	20 ft. Yaw	Temp. of Barrel
40	M1 Ball	2500	-	0					
41			-	0					
42			-	0					
43			-	0					
44			-	0					
45			-	0					
46			233	3.5	-	0	-	0	Heated
47			0	0	-	0	-	0	
48			161	1.5	-	0	-	0	
49			0	0	-	0	-	0	
50	2476-C	2500	0	0	-	0	-	0	
51			0	0	-	0	-	0	
52			0	-	-	0	-	0	
53			276	3.5	-	0	-	0	
54			0	-	-	0	-	0	Heated
55	M1 Ball	2900	198	10.0	245	3.5	154	8.5	
56			288	3.5	-	-	-	-	
57			-	0	-	-	-	-	
58			-	0	-	-	-	-	
59			-	-	-	-	-	-	
60			344	2.8	-	-	-	-	
61			-	-	-	-	-	-	
62			-	-	-	-	-	-	
63			294	7.0	-	-	78	4.2	
64			-	-	-	-	-	-	
65			-	-	-	-	-	-	
66			201	3.5	-	-	329	4.2	
67			-	-	-	-	-	-	Heated
68			-	-	-	-	-	-	
69			223	2.8	-	-	348	4.2	
70	M1 Ball	2500	-	-	-	-	-	-	
71			-	-	-	-	-	-	
72			-	-	-	-	-	-	
73			-	-	-	-	-	-	
74			-	-	-	-	-	-	

Table V

Orientation and Yaws Obtained in Firing of Hot Gun of 1 in 12" Twist

Rd. No.	Bullet	Vel. (Est)	10 ft. Orientation	10 ft. Yaw	13 ft. Orientation	13 ft. Yaw	20 ft. Orientation	20 ft. Yaw	Temp. of Barrel
75	M1 Ball	2500	-	-			-	-	Heated
76			-	-			-	-	
77			-	-			-	-	
78			-	-			-	-	
79			-	-			-	-	
80			-	-			-	-	
81			-	-			-	-	
82			-	-			-	-	
83			-	-			-	-	
84			-	-			-	-	
85	M1 Ball	2900	321	9.6			292	11.2	Heated
86			-	-			-	-	
87			-	-			-	-	
88			-	-			-	-	
89			164	5.4			-	-	
90			-	-			-	-	
91			86	5.4			227	6.5	
92			201	7.0			345	6.0	
93			-	-			-	-	
94			-	-			17	4.2	
95			351	6.5			137	6.5	
96			-	-			-	-	
97			-	-			-	-	
98			-	-			-	-	
99			-	-			-	-	
100	M1 Ball	2500	-	-			-	-	Room Temperature
101			-	-			-	-	
102			-	-			-	-	
103			-	-			-	-	
104			161	3.5			-	-	
105			-	-			-	-	
106			185	6.0			-	-	
107			-	-			-	-	
108			-	-			-	-	
109			199	5.2			350	4.2	

Table V

Orientation and Yaws Obtained in Firing of Hot Gun of 1 in 12" Twist

Rd. No.	Bullet	Vel. (Est)	10 ft. Orientation	10 ft. Yaw	13 ft. Orientation	13 ft. Yaw	20 ft. Orientation	20 ft. Yaw	Temp. of Barrel
110	M1 Ball	2500	-	-			-	-	Room Temperature
111			-	-			-	-	
112			-	-			-	-	
113			-	-			-	-	
114			-	-			-	-	
115		2900	128	4.2			102	6.0	
116			-	-			-	-	
117			-	-			-	-	
118			222	4.8			199	4.2	
119			9	4.8			167	3.5	
120			-	-			-	-	
121			202	3.5			349	3.5	
122			-	-			-	-	
123			213	7.0			4	8.0	
124			-	-			-	-	
125			219	5.4			-	-	
126			-	-			-	-	
127			220	7.6			15	4.8	
128			-	-			-	-	
129			202	3.5			344	2.8	
130		2500	-	-			-	-	Heated
131			31	5.2			184	4.2	
132			-	-			-	-	
133			-	-			-	-	
134			209	3.5			-	-	
135			212	5.2			169	3.5	
136			-	-			-	-	
137			356	2.8			-	-	
138			-	-			-	-	
139			247	2.8			-	-	
140		3000	86	19.4			54	21.4	
141			74	12.2			35	10.0	
142			151	18.6			121	19.4	
143			191	11.2			163	10.8	
144			174	11.2			139	11.8	

Table V

Orientation and Yaws Obtained in Firing of Hot Gun of 1 in 12" Twist

Rd.	Bullet	Vel. (Est)	10 ft. Orient-ation	10 ft. Yaw	13 ft. Orient-ation	13 ft. Yaw	20 ft. Orient-ation	20 ft. Yaw	Temp. of Barrel
145	M1 Ball	3000	19	6.5			169	4.2	Heated
146			157	10.8			127	11.2	
147			126	12.2			94	12.4	
148			-	-			-	-	
149			118	8.5			86	8.4	
			-				-		
151			219	11.6			179	11.8	
152			166	10.8			132	11.2	
153		2500	-	0			-	0	
154			-	0			-	0	
155			179	4.8			-	0	
156			-	0			-	0	

300 rounds fired maintaining muzzle temperature at 178 C.
No measurements taken.

Rd.	Bullet	Vel. (Est)	10 ft. Orient-ation	10 ft. Yaw	13 ft. Orient-ation	13 ft. Yaw	20 ft. Orient-ation	20 ft. Yaw	Temp. of Barrel
457	M1 Ball	2500	117	10.2			80	8.8	Heated
458			339	2.2			-	0	
459			-	0			-	0	
460			-	0			-	0	
461			-	0			-	0	

300 rounds fired maintaining muzzle temperature at 178 C.
No measurements taken.

Rd.	Bullet	Vel. (Est)	10 ft. Orient-ation	10 ft. Yaw	13 ft. Orient-ation	13 ft. Yaw	20 ft. Orient-ation	20 ft. Yaw	Temp. of Barrel
762	M1 Ball	2500	177	3.5			-	0	Heated
763			226	4.2			-	0	
764			-	0			-	0	
765			177	10.8			150	9.2	
766			-	0			-	-	
767			237	9.2			201	4.2	

400 rounds fired maintaining muzzle temperature at 178 C.
No. measurements taken.

Rd.	Bullet	Vel. (Est)	10 ft. Orient-ation	10 ft. Yaw	13 ft. Orient-ation	13 ft. Yaw	20 ft. Orient-ation	20 ft. Yaw	Temp. of Barrel
1168	M1 Ball	2500	-	0			-	-	Heated
1169			106	13.6			66	13.4	
1170			277	14			242	14.2	
1171			331	15.8			29	16.6	
1172			217	10.6			178	8.8	
1173			209	16.2			170	18.1	

Table V

Orientation and Yaws Obtained in Firing of Hot Gun of 1 in 12" Twist

Rd. No.	Bullet	Vel. (Est)	10 ft. Orient-ation	10 ft. Yaw	13 ft. Oriont-ation	13 ft. Yaw	20 ft. Orient-ation	20 ft. Yaw	Temp. of Barrel
1174	M1 Ball	2500	-	0			-	-	Room Temperature
1175			-	0			-	-	
1176			-	0			-	-	
1177			91	4.2			-	-	
1178			167	11.6			128	7	
1179			211	39			-	-	
1180			244	4.2			-	-	
1181			255	12.4			222	11.6	
1182			229	10.8			293	8.0	
1183			-	-			-	-	
1184			-	-			-	-	
1185			-	-			-	-	
1186			186	4.2			-	-	
1187			-	-			-	-	
1188			-	-			-	-	
1189			-	-			-	-	
1190			-	-			-	-	
1191			-	-			-	-	
1192			278	4.2			-	-	
1193	2476-A	2500	-	-			-	-	
1194			260	5.4			-	-	Room Temperature
1195			-	-			-	-	
1196			211	4.8			-	-	
1197			-	-			-	-	
1198	2476-B	2500	-	-			-	-	
1199			-	-			-	-	
1200			-	-			-	-	
1201			197	2.8			-	-	Room Temperature
1202			-	-			-	-	
1203	2476-C	2500	-	-			-	-	
1204			229	2.2			-	-	
1205			-	-			-	-	
1206			-	-			-	-	
1207			-	-			-	-	
1208	2476-A	2500	-	-			-	-	Heated
1209			-	-			-	-	

Table V

Orientation and Yaws Obtained in Firing of Hot Gun of 1 in 12" Twist

Rd. No.	Bullet	Vel. (Est)	10 ft. Orient-ation	10 ft. Yaw	13 ft. Orient-ation	13 ft. Yaw	20 ft. Orient-ation	20 ft. Yaw	Temp. of Barrel
1210	2476-A	2500	-	-			-	-	Heated
1211			262	5.4			-	-	
1212			18	6.0			-	-	
1213			28	7.0			-	-	
1214			194	11.6			151	9.2	
1215			172	16.2			135	12.8	
1216			330	7.6			-	-	
1217			-	-			-	-	
1218	2476-B	2500	315	4.2			-	-	
1219			242	8.8			204	4.2	
1220			-	-			-	-	
1221			-	-			-	-	
1222			38	7.6			-	-	
1223			306	14.8			263	12.2	
1224			-	-			-	-	
1225			-	-			-	-	
1226			327	13.4			293	11.2	
1227			-	-			-	-	
1228	2476-C	2500	71	5.4			-	-	Heated
1229			242	8.0			-	-	
1230			158	4.2			-	-	
1231			141	4.2			-	-	
1232			257	6.5			-	-	
1233			-	-			-	-	
1234			-	-			-	-	
1235			-	-			-	-	
1236			-	-			-	-	
1237			-	-			-	-	

Table VI

Orientation and Yaws Obtained in Firing of Hot Gun of 1 in $14\frac{1}{2}$" Twist

Rd. No.	Bullet	Vel (Est)	10 ft. Orient-ation	10 ft. Yaw	15 ft. Orient-ation	15 ft. Yaw	20 ft. Orient-ation	20 ft. Yaw	Temp. of Barrel
1	MI Ball	2500	-	-	-	-	-	-	Heated
2			-	-	-	-	-	-	
3			-	-	-	-	-	-	
4			-	-	-	-	-	-	
5			-	-	-	-	-	-	
6			-	-	-	-	-	-	
7			-	-	-	-	-	-	
8			-	-	-	-	-	-	
9			-	-	-	-	-	-	
10			-	-	-	-	-	-	
11		2900	210°	5.4	289°	2.8	-	0	
12			-	-	-	-	-	-	
13			-	-	-	-	-	-	
14			-	-	-	-	-	-	
15			-	-	-	-	-	-	
16			-	-	-	-	-	-	
17			184	7.5	[illegible]	7.5	-	0	
18			-	-	-	-	-	-	
19			-	-	-	-	-	-	
20			-	-	-	-	-	-	
	200 rounds fired maintaining muzzle temperature at 178° C. No measurements taken.								
221	MI Ball	2500	-	0	-	0	-	0	Heated
222			153°	1.4	217°	1.4	-	0	
223			257	3.5	318	2.2	-	0	
224			188	2.8	261	3.5	-	0	
225			-	0	-	0	-	0	
226			-	0	-	0	-	0	
227			-	0	-	0	-	0	
228			-	0	-	0	-	0	
229			205	7.1	274	6.5	348°	1.4	
230			185	4.8	245	5.4	-	0	
231		2900	288	2.8	355	2.8	-	0	
232			294	14.2	2	10.6	-	0	
233			208	16.9	277	11.5	-	0	
234			-	0	-	0	-	0	
235			190	7.0	257	6.5	-	0	
236			-	-	-	0	-	0	
237			-	0	-	0	-	0	
238			-	0	-	0	-	0	
239			268	4.1	340	4.1	-	0	
240			287	4.1	358	4.1	-	0	

Table VI

Orientation and Yaws Obtained in Firing of Hot Gun of 1 in 14½" Twist

Rd. No.	Bullet	Vel. (Est)	10 ft. Orientation	10 ft. Yaw	15 ft. Orientation	15 ft. Yaw	20 ft. Orientation	20 ft. Yaw	Temp. of Barrel
441	MI Ball	2500	-	0	-	0	-	0	Heated
442			291°	0	349°	4.1	-	0	
443			97	6	159	-	-	0	
444			191	-	250	6	312°	-	
445			-	0	-	0	-	0	
446			12	8.5	73	8.5	-	0	
447			-	0	-	0	-	0	
448			-	0	-	0	-	0	
449			-	0	-	0	0	0	
450			76	6.0	140	6.5	207	2.8	
451		2900	90	9.8	156	8.0	-	0	
452			261	19.1	330	12.7	-	0	
453			333	14.8	37	10.6	-	0	
454			155	8.5	220	8.0	-	0	
455			72	25.2	138	15.9	-	0	
456			[illegible]	7.0	[illegible]	6.5	-	0	
457			276	16.6	339	11.8	-	0	
458			219	16.6	282	11.5	-	0	
459			325	4.7	20	3.5	-	0	
460			72	9.9	13[illegible]	8.5	-	0	

200 rounds fired maintaining muzzle temperature at 178° C
No measurements taken.

Rd. No.	Bullet	Vel. (Est)	10 ft. Orientation	10 ft. Yaw	15 ft. Orientation	15 ft. Yaw	20 ft. Orientation	20 ft. Yaw	Temp. of Barrel
661	M1 Ball	2500	-	0	-	0	-	0	Heated
662			-	0	-	0	-	0	
663			264	3.5	326	3.5	-	0	
664			-	0	-	0	-	0	
665			46	3.5	106	4.1	-	0	
666			-	0	-	0	-	0	
667			53	15.9	121	11.5	-	0	
668			177	6.5	241	4.8	-	0	
669			162	9.9	223	8.8	290	4.8	
670			-	0	-	0	-	0	

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Table VI

Orientation and Yaws Obtained in Firing of Hot Gun of 1 in $14\frac{1}{2}$" Twist

Rd. No.	Bullet	Vel. (Est)	10 ft. Orientation	10 ft. Yaw	15 ft. Orientation	15 ft. Yaw	20 ft. Orientation	20 ft. Yaw	Temp. of Barrel
671	M1 Ball	2900	208°	26.8	275°	17.6	-	0	Heated
672			235	13.4	307	9.9	-	0	
673			160	7.6	221	6.5	-	0	
674			22	4.8	-	0	-	0	
675			223	4.1	289	3.5	-	0	
676			189	7.0	254	6.5	-	0	
677			-	0	-	0	-	0	
678			202	8.9	270	6.5	-	0	
679			3	5.4	67	3.5	-	0	
680			45	13.0	117	8.9	-	0	
681	Cal. .50 Tracer (Modif. No. 1)	2500	122	7.3	195	2.7	-	0	
682			297	2.7	-	0	-	0	
683			-	0	-	0	-	0	
684			-	0	-	0	-	0	
685		2900	-	0	-	0	-	0	
686			322	3.6	[illegible]	1.0	-	0	
687			[illegible]	[illegible]	-	0	-	0	
688			357	2.2	-	0	-	0	
689	M1 Ball	2500	-	0	-	0	-	0	
690			-	0	-	0	-	0	
691			173	1.6	-	0	-	0	
692			-	0	-	0	-	0	
693			-	0	-	0	-	0	
694		2900	155	3.1	-	.0	-	0	
695			-	0	-	0	-	0	
696			-	0	-	0	-	0	
697			-	0	-	0	-	0	
698			-	0	-	0	-	0	

200 rounds fired maintaining muzzle temperature at 178° C.
No measurements taken.

Rd. No.	Bullet	Vel. (Est)	10 ft. Orientation	10 ft. Yaw	15 ft. Orientation	15 ft. Yaw	20 ft. Orientation	20 ft. Yaw	Temp. of Barrel
899	M1 Ball	2500	21	.7	98	.7	-	0	Heated
900			266	0	-	0	-	0	
901			[illegible]	7.0	192	6.5	260°	4.8	
902			198	1.5	260	2.1	-	0	
903			128	6.0	206	6.5	259	2.8	
904			357	4.8	54	5.4	125	2.8	
905			-	0	-	0	-	0	
906			-	0	-	0	-	0	
907			-	0	-	0	-	0	
908			-	0	-	0	-	0	

Table VI

Orientation and Yaws Obtained in Firing of Hot Gun of 1 in 14½" Twist

Rd. No.	Bullet	Vel. (Est)	10 ft. Orientation	10 ft. Yaw	15 ft. Orientation	15 ft. Yaw	20 ft. Orientation	20 ft. Yaw	Temp. of Barrel
909	MI Ball	2900	177°	24.3	242°	16.4	-	0	Heated
910			255	4.1	325	4.1	-	0	
911			130	2.8	197	2.2	-	0	
912			60	14.2	130	10.2	-	0	
913			-	0	-	0	-	0	
914			258	2.8	330	0	-	0	
915			293	11.8	359	8.9	-	0	
916			134	6.5	201	5.4	-	0	
917			103	6.5	158	4.8	-	0	
918			288	7.5	346	6.5	-	0	
200 rounds fired maintaining muzzle temperature at 178° C No measurements taken.									
1119	MI Ball	2500	149	2.2	217	2.9	-	0	Heated
1120			200	1.5	268	2.2	-	0	
1121			240	7.0	306	8.0	17	2.2	
1122			-	0	-	0	-	0	
1123			-	0	-	0	-	0	
1124			-	0	-	0	-	0	
1125			-	0	-	0	-	0	
1126			-	0	-	0	-	0	
1127			183	2.2	248	3.5	316°	.7	
1128			-	0	-	0	-	0	
1129		2900	19	22.8	84	14.8	-	0	
1130			33	11.5	97	8.5	-	0	
1131			-	0	30	7.5	-	0	
1132			18	3.5	80	4.8	-	0	
1133			56	13.5	120	9.3	-	0	
1134			182	8.5	241	7.0	306	.7	
1135			315	8.9	13	7.6	85	.7	
1136			340	9.6	40	8.0	104	.7	
1137			196	13.6	262	10.2	-	0	
1138			173	10.2	236	8.0	308	3.5	
1139	MI Ball	2500	-	0	-	0	-	0	Room Temperature
1140			114	3.5	174	3.5	-	0	
1141			-	0	-	0	-	0	
1142			-	0	-	0	-	0	
1143			108	1.5	165	2.2	-	0	
1144			-	0	270	1.5	326	.7	
1145			-	0	-	0	-	0	
1146			26	2.8	100	2.8	-	0	
1147			182	3.5	240	3.5	308	1.5	
1148			-	0	-	0	-	0	

Table VI

Orientation and Yaws Obtained in Firing of Hot Gun of 1 in 14½" Twist

Rd. No.	Bullet	Vel. (Est)	10 ft. Orientation	10 ft. Yaw	15 ft. Orientation	15 ft. Yaw	20 ft. Orientation	20 ft. Yaw	Temp. of Barrel
1149	MI Ball	2900	143°	6.5	210°	5.4	288°	.7	Room Temperature
1150			-	0	-	0	-	0	
1151			-	0	-	0	-	0	
1152			253	2.2	310	2.2	-	0	
1153			-	0	-	0	-	0	
1154			105	3.5	171	2.8	-	0	
1155			-	0	-	0	-	0	
1156			257	2.2	319	.7	-	0	
1157			-	-	-	0	-	0	
1158			94	1.5	153	1.5	-	0	

Table VII

Additional Firings in Hot Gun of 1 in 14-1/2" Twist

Comparison of Yaws Obtained with 5 Types of Bullets

Velocity - 2900 f/s (Est)

Test Rd. No.	Type of Bullet	Dist. from Muzzle 10 ft.		Dist. from Muzzle 15 ft.	
		Yaw	Orientation	Yaw	Orientation
1	MI Tracer	7.3°	150°	0	209°
2		0	-	0	-
3		1.7	227	0	-
4		3.6	275	0	-
5		3.6	106	0	-
6		4.5	322	0	-
7		3.2	241	0	-
8		1.7	298	0	-
9		0	-	0	-
10		0	-	0	-
11		0	-	0	-
12		0	-	0	-
13		0	-	0	-
14		0	-	0	-
15		.5	236	0	-
16		0	-	0	-
17		3.2	93	0	-
18		2.2	108	0	-
19		3.6	294	0	-
20		0	-	0	-
21	MI Tracer (Modif.2601-C)	0	-	0	-
22		6.1	348	0	52
23		4.0	340	0	43
24		6.5	299	0	8
25		0	-	0	-
26		4.5	52	0	-
27		0	-	0	-
28		2.7	337	0	-
29		.5	339	0	-
30		0	-	0	-
31		.5	246	0	-
32		0	-	0	-
33		3.1	267	0	-
34		2.2	356	0	-
35		0	-	0	-

Table VII

Additional Firings in Hot Gun of 1 in 14-1/2" Twist

Comparison of Yaws Obtained with 5 Types of Bullets

Velocity - 2900 f/s (Est)

Test Rd. No.	Types of Bullet	Dist. from Muzzle 10 ft. Yaw	Dist. from Muzzle 10 ft. Orientation	Dist. from Muzzle 15 ft. Yaw	Dist. from Muzzle 15 ft. Orientation
36	MI Tracer (Modif.2601-C)	0	-	0	-
37		4.9	337	0	-
38		0	-	0	-
39		0	-	0	-
40		0	-	0	-
41	MI Ball	4.1	284	0	-
42		3.5	216	0	-
43		4.1	182	0	-
44		8.5	317	0	-
45		3.5	299	0	-
46		2.8	310	0	-
47		2.8	321	0	-
48		2.8	237	0	-
49		0	-	0	-
50		6.5	237	0	-
51		4.8	4	0	-
52		6.0	309	0	-
53		2.8	201	C	-
54		Two bullets in one hole			
55		"	" " "	"	16
56		6.0	243	0	300
57		3.5	10	0	60
58		2.2	233	0	-
59		7.0	211	0	280
60		0	-	0	-
61	MI Tracer (Modif. 2601-D)	0	-	0	-
62		0	-	0	-
63		2.2	353	0	-
64		4.5	280	0	-
65		1.1	249	0	-
66		0	-	0	-
67		4.9	300	0	-
68		1.1	303	0	-
69		3.6	333	0	-
70		2.7	217	0	304

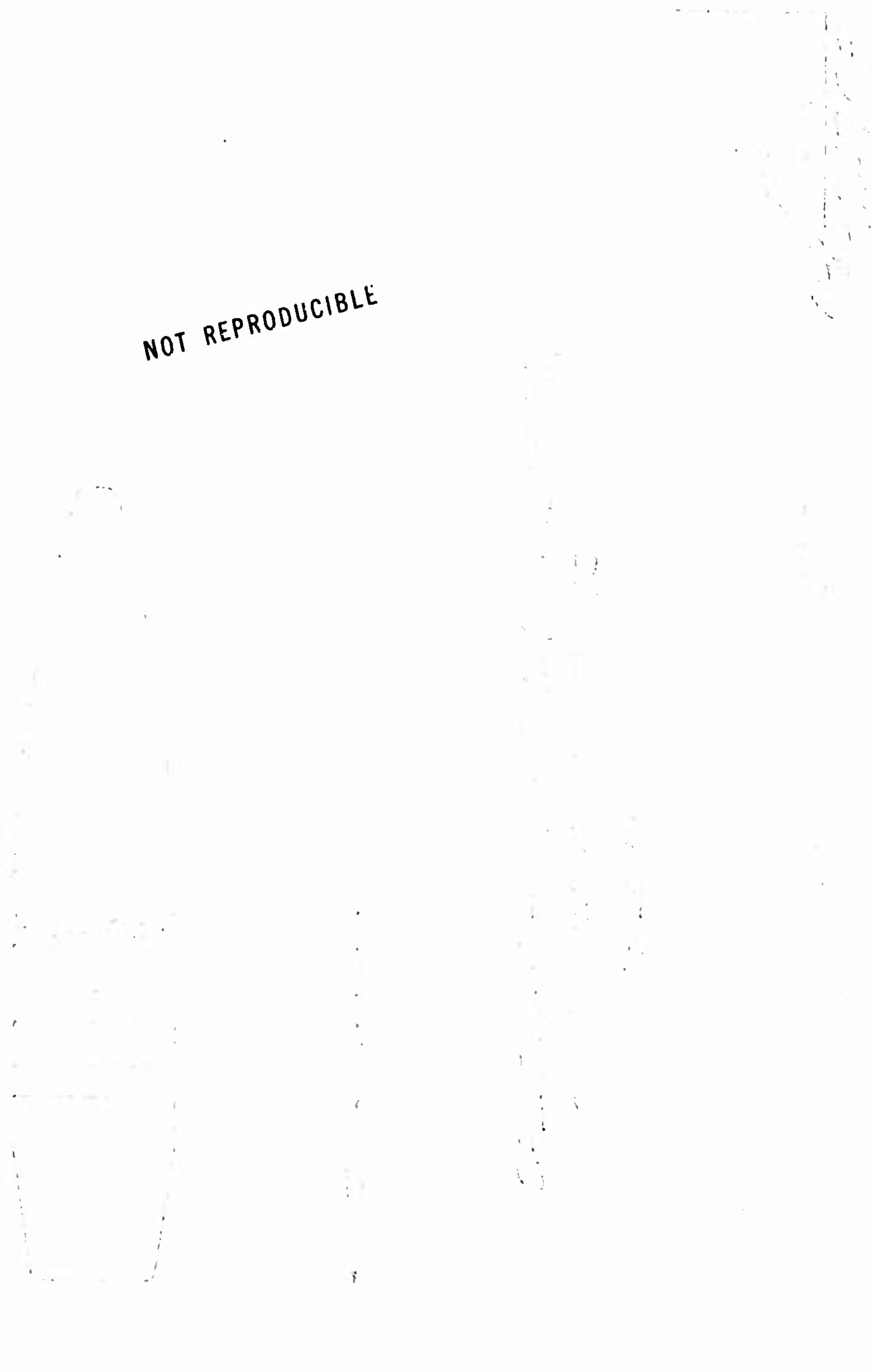
Table VII

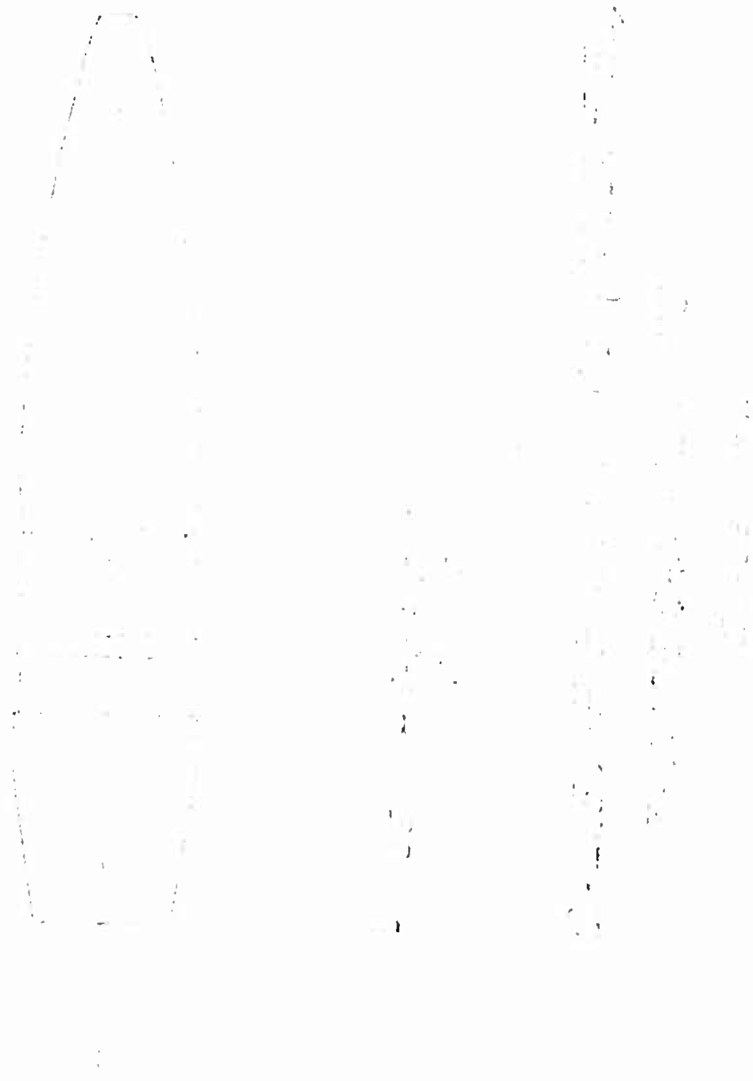
Additional Firings in Hot Gun of 1 in 14-1/2" Twist

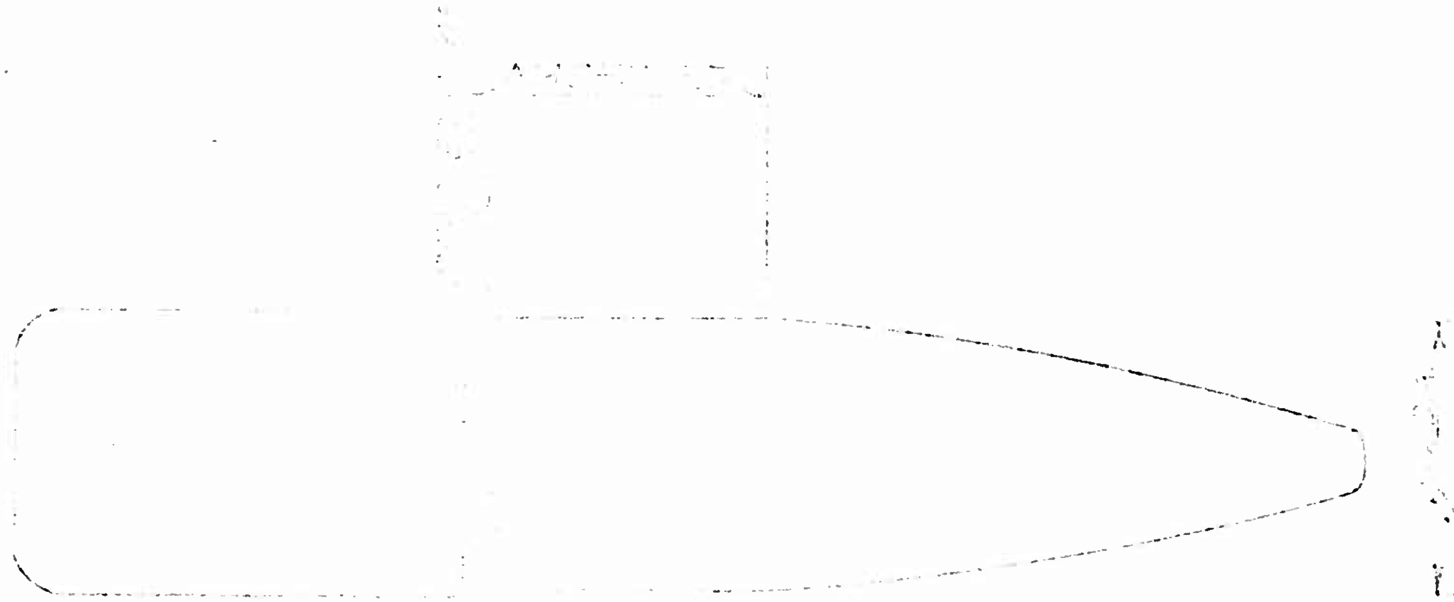
Comparison of Yaws Obtained with 5 Types of Bullets

Velocity - 2900 f/s (Est)

Test Rd. No.	Type of Bullet	Dist. from Muzzle 10 ft. Yaw	Orientation	Dist. from Muzzle 15 ft. Yaw	Orientation
71	MI Tracer	2.2	170	0	-
72	(Modif. 2601-D)	2.2	241	0	-
73		4.5	222	0	-
74		.5	222	0	-
75		1.6	160	0	-
76		-	201	0	-
77		0	-	0	-
78		4.5	300	0	-
79		2.7	5	0	-
80		3.6	325	0	38
81	MI Ball	7.0	272	0	340
82	(Modif.2476-A)	6.5	255	0	317
83		8.5	280	0	342
84		-	0	0	-
85		4.6	140	0	204
86		8.5	219	0	285
87		6.0	212	0	280
88		0	-	0	-
89		5.4	222	0	232
90		13.0	235	0	30[illegible]
91		9.6	161	0	227
92		4.8	235	0	296
93		5.4	158	0	227
94		6.5	186	0	-
95		7.0	223	0	-
96		4.8	203	0	264
97		7.0	164	0	226
98		0	135	7.0	198
99		5.4	158	0	203
100		0	90	6.5	158







[illegible] BULLET - CAL. .50

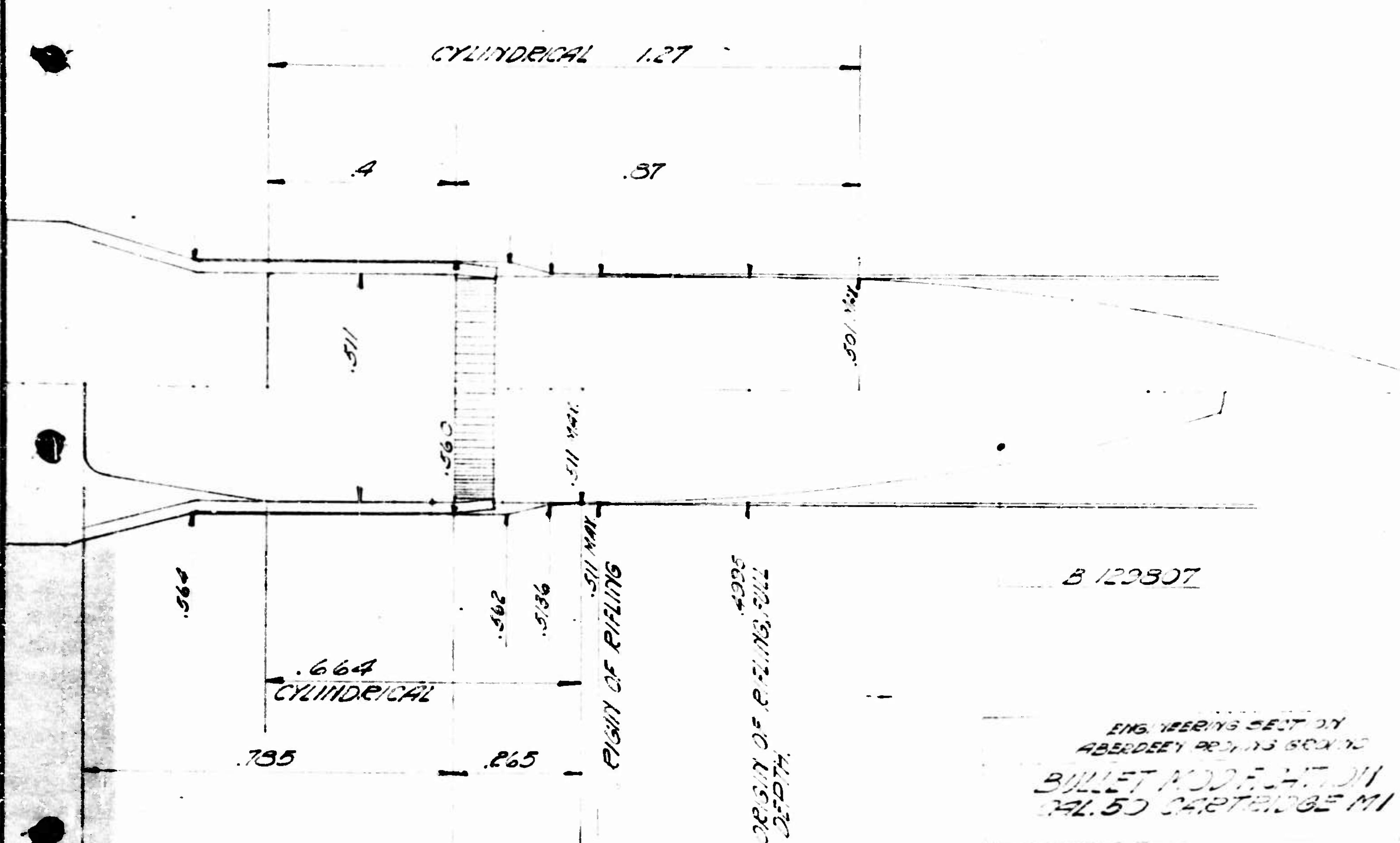
[illegible] 2/28/57

[illegible] BY DIMENSIONS

SCALE 1 = 3

[illegible] SECTION

[illegible] GROUND [illegible] 1952 [illegible]



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ENGINEERING SECTION
ABERDEEN PROVING GROUND

BULLET MODIFICATION
CAL. .50 CARTRIDGE M1

SUBMITTED	
EXAMINED	
APPROVED	ORD DEPT USA 3-25-36
	COL. ORD DEPT USA COMMANDING